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Victair Mistifier Gearbox: Metal Casted Housing

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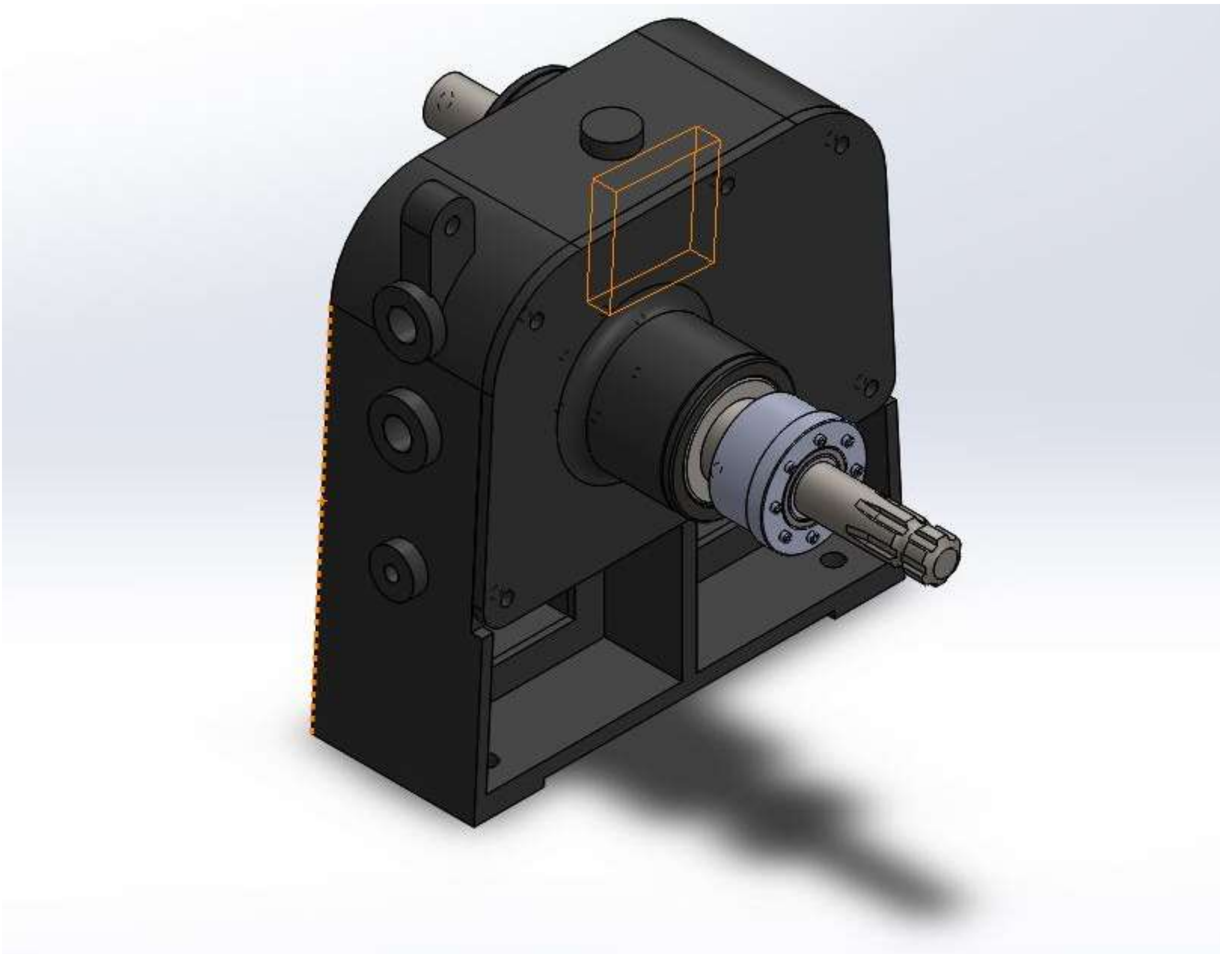
Victair Mistifier Gearbox:
Metal Casted Housing



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MET SENIOR PROJECT

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INTRODUCTION

Abstract

The current global population is 7.2 billion. It is projected to increase by 1 billion over the next 12 years. There is only 5% of usable farming land left on earth. Food is a resource that humans must consume daily. These facts undeniably lead to a shortage of food in the future. It is essential to mankind survival that farming becomes more efficient and sustainable. This provided the motivation to design a more efficient transmission for the Victair Mistifier (orchard and vineyard sprayer). Victair Mistifiers are designed, engineered, and manufactured by H.F. Hauff Company in Yakima, WA. The Hauff Company's commitment to manufacturing the best sprayer on the market accompanied with the desire to address sustainable farming, are the driving forces behind this project. The scope of the project is to design, develop, and test a gearbox that optimizes the overall function of the sprayer. The gearbox simplifies the overall design of the sprayer, by replacing 19 major components with 8. This design decreases material costs, increases manufacturability, and decreases assembly time. The gearbox receives power from the tractor's power take-off (PTO) via the input shaft. It transmits the power through machine elements to two shafts that will power fans. The fans will spin in opposite directions at an equal, desired rotational speed. The transmission will be enclosed in an engineered metal casted housing. The gearbox design was proven, by the prototype, to perform to specifications while maintaining an oil temperature of less than 90 degrees Celsius.

Motivation

Victair Mistifiers are designed, engineered, and manufactured by H.F. Hauff Company, Inc. in Yakima, WA. Victair Mistifiers have been manufactured and sold since 1965. Hauff's commitment to manufacturing the best sprayer on the market is the driving motivation of this project.

The engineering of this gearbox is to optimize the overall design and function of the Victair Mistifier orchard and vineyard sprayer. This dual output gearbox is specifically motivated by lean manufacturing. The gearbox will simplify the overall design of the sprayer. It is replacing 19 major components with 8, which will decrease the overall cost of the system. This will make the system easier and cheaper to manufacture, by saving assembly time, and materials.

Function Statement

The gearbox receives power from the tractor's power take-off (PTO) via the rotating input shaft. It transmits the power through machine elements to two shafts that will power fans. The fans will spin in opposite directions at an equal, desired rotational speed. The transmission will be enclosed in an engineered metal casted housing.

Requirements
The requirements for this device to function effectively are as follows:

- Specs: $n_{input} \approx 540\ rpm;\ n_{output} = 1944\ rpm\ \pm 50\ rpm; Pwr_{in} = 35 - 60HP$
- Size: Must be able to fit on to the trailer, between the fans.
    - Spatial Requirement of < 18”X24”X24”
- Weight: Cannot cause the trailer to be out of balance
    - Weight Requirement of < 100 lbs
- Cost: Must be cheaper to manufacture than to buy the Bima Box.
    - <$990.00
- Heat Dissipation: Temperature inside the gearbox cannot be greater than 90°C or 194°F
- Function: No leaks in 8 hours of operation. Must contain all shafts, seals, bearings, and gears with clearance of no less than .375 in at the closest point.
- Must include a tab on the top of the gearbox to fit the handle mechanism assembly. This assembly allows the operator the ability to rotate the fans. The geometry and tolerances will abide by the existing gearbox drawing.
- Must have a base as part of the casting in order for the gearbox to be securely mounted to the trailer.
- Must support the fans via collars. Geometry of the collars are as follows:
  OD x ID x Length = 4.313 + .000 – .002 in X 3.347 ± .005 X 3.350 ± .020
- Must have a fill/vent hole, spy hole, and drain hole.

Engineering Merit
Engineering optimization for the design of the housing will stem from both function and production.

The function of the housing is to enclose the gears and components of the gearbox. It must support the bearings and seals, supply ample lubrication to all mating surfaces, and dissipate the frictional heat. Optimization for the housing function will occur in the form of material selection and geometry. Both material selection and geometry will be analyzed to determine that the housing is able to support the radial and axial forces of the gearbox’s inner components. Geometry of the housing will be analyzed to determine lubrication method and type. Frictional heat will be calculated and material selection and geometry will be analyzed to determine if fins will be necessary.

The production of the housing will be optimized with lean manufacturing being the leading factor. The housing will be produced by a metal casting process. Mold design will be analyzed to optimize for the fastest and easiest machine time (clean up time) of the casting. However, the job of casting the gearbox will be outsourced to a foundry. The foundry and the pattern makers will be held responsible to meet the specs of the part drawing with the finished product, as well as creating a casting that is easily and effectively machined.

Focus
The Victair Mistifier gearbox is a team project. The component of the gearbox that will be focused on in this paper is the metal casted housing. The gear train will be engineered by Casey McFarlen, and the shafts, bearings, and seals will be engineered by Ricky Skinner.

Success Criteria

The success depends on the final performance and cost efficient manufacturability of the gearbox. All specs provided by Neil Hauff for the rotational speeds must be met, and the gearbox must be able to be manufactured at a lower cost than the system that the Mistifier currently operates with.

The success criteria for this gearbox is that it is assembled as a prototype and operates off a tractor's PTO for 2 hours without any catastrophic breakdowns.

DESIGN AND ANALYSIS

Proposed Solution

Neil Hauff provided the basic design for the gear train and subsequently the housing (*Figure 1*). He gave the advice and industry insight to design the gear train components first and build the housing around them. Originally we had planned on a vertical gear train design, but after further thought concerning lubrication, a horizontal gear train seemed to be a better solution (*Figure 3*). After trying to configure a few more designs, it was realized that the solution was as simple as it had appeared. The design went full circle and back to the original design (*Figure 2*).

Description

The design for a metal cast gearbox housing must ensure that the components (shafts, gears, bearings, and seals) will be supported, the gears will have room to spin without interference, be provided with ample lubrication, and that the frictional heat created in the gearbox will be dissipated.

The figure below is a simplified sketch of how the gearbox housing will look (*Figure 1*). This the drawing that Neil made that got us started on the project. The gearbox will be two pieces: a casted housing and a fabricated plate that will mate vertically to the housing. Figures 2 and 3 show the various sketches that our team made in an effort to pinpoint what design we would end up pursuing.

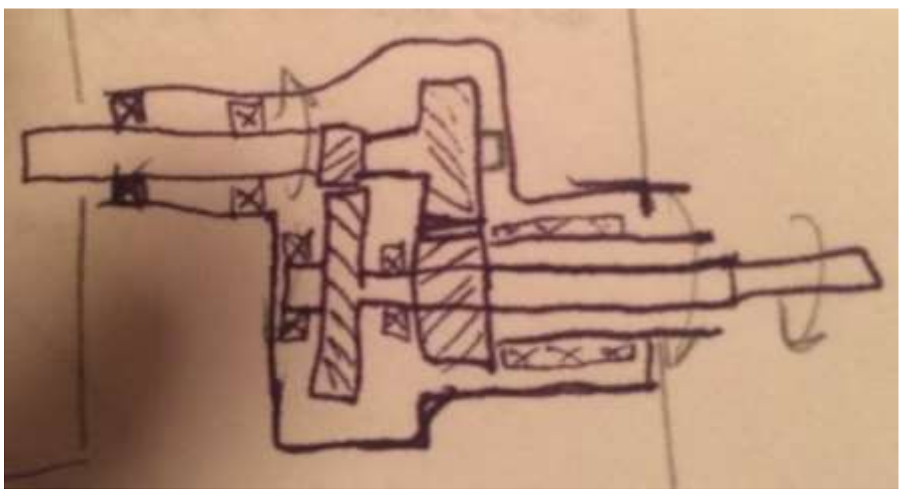

Fig. 1 – Neil's initial sketch of gearbox

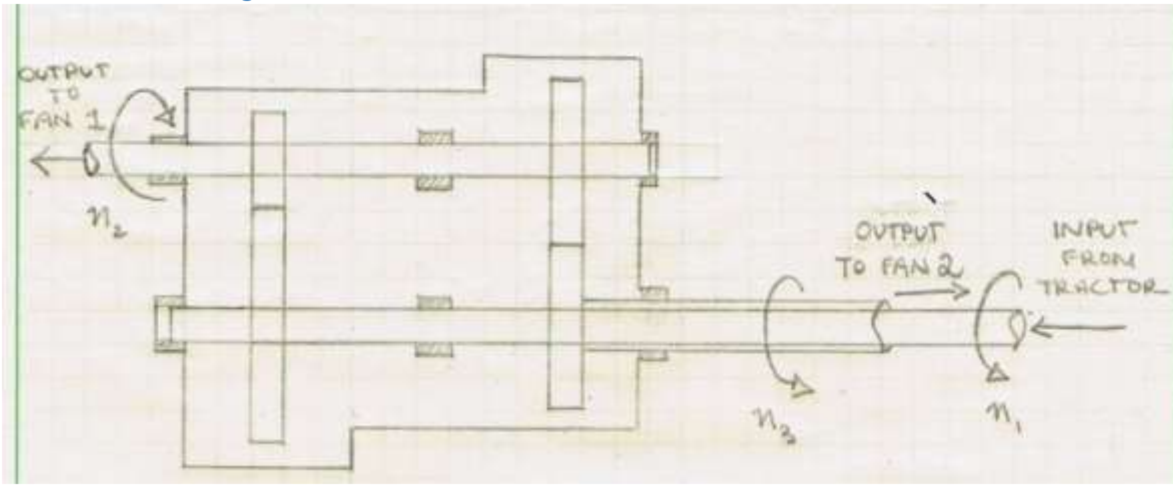

Fig. 2 – 1st sketch of the gearbox

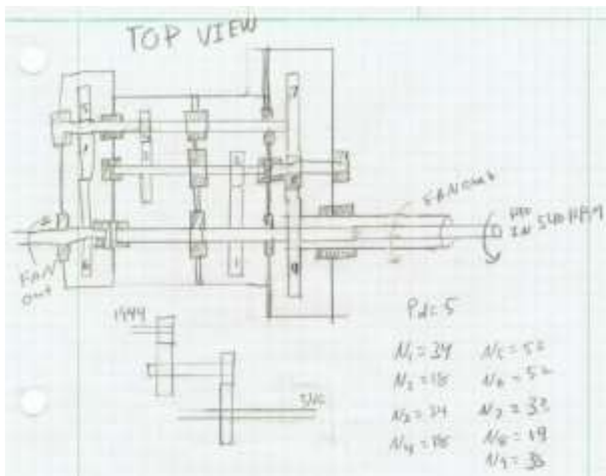

Fig. 3 – 2nd sketch of the gearbox

The gears, shafts, bearings, and mating geometry has changed from design to design. Because the housing must encase the inners, it is the last piece of the puzzle that gets changed. It has undergone another design change to accommodate said parts. See pictures in Appendix B for the evolution of the gearbox design.

The final design of the gearbox was actually design five. It is a single piece casting that has a base incorporated in it. Its right side is open and a fabricated plate and tube weldment will be fastened to the housing to seal it after the components are assembled inside.

Benchmark

Neil provided us with a unique design for the gearing and shaft set up for the gearbox. The gearbox housing was built in close accordance to the existing gearbox design in order for ease of production and compatibility with the other components on the sprayer. The benchmark for the housing design was the Victair Mistifier Gear Housing Part #14552.

Performance Predictions

The gear box housing is predicted to be well under spatial requirements. It is predicted to provide ample support and lubrication for the gearbox components. It is further predicted that the housing will be able to dissipate frictional heat created in the gearbox; so that the gearbox can run for up to 8 hours in one time lapse, under direct sun, at an ambient temperature of 110°F without exceeding a surface temperature of 190°F

Description of Analyses

Analyses will be performed two-fold:

1. Function of the housing geometry

The function of the housing geometry will be analyzed in three ways; it will be designed and optimized to support the forces that occur at the bearings, it will be optimized to accommodate an oil that can efficiently lubricate all components, and it will be optimized to efficiently dissipate the frictional heat caused by mechanical inefficiencies in operation.

2. Lean manufacturing production.

The lean manufacturing production of the housing will be analyzed in method of construction, machining, and commonality in geometry between existing components and the new gearbox.

Scope of Testing and Evaluation

The gearbox will be tested to meet the requirements listed in the beginning of the proposal:

- Rotational speeds of the input and output shafts will be measured to insure they meet spec.
- The overall dimensions of the gearbox will be measured to insure that all existing components that fit on the shaft can still properly operate. It will also be measured to insure it is within the spatial requirement.
- The gearbox will be weighed to insure it is within spec for the weight requirement.
- A product cost analysis will be run on the new gearbox vs. the old set up, in order to determine that the new design is indeed a cheaper method of manufacturing.
- The temperature of the gearbox will be measured in operation to determine the heat dissipation of the gearbox.
- Visual inspection will be performed to insure no leaks in the gearbox.

Analysis

Proposed Sequence

A design of the gearbox will be made to enclose and support the gears, seals, bearings, and shafts. Then geometry will be added for the base, bosses to support the fans, and the handle mechanism tab. Once an understanding of the design is made, then analysis into how it can be cast will occur. After calculations and analysis for the design are complete and signed off by Neil, then prototype fabrication can begin.

A prototype housing will closely model the cast housing design. It will be fabricated by the Hauff team at their shop. After extensive testing of the prototype housing, changes will be made where needed and a revised casting design will be created.

The revised casting design will be sent out to a job shop foundry and work on designing the casting method and mold design for the housing will occur. SolidCast or other simulators are typically used for further animated analysis. When the mold design passes, then pattern design will occur. Typically, the process from revised casting drawings submission to an actual part is a three month out job, dependent on the work load of the foundry.

Function

Support

The radial forces of the gears were calculated to determine the bearing and shaft sizes. The forces on the housing are equal to the forces on the bearings. As the bearings are supported by the housing. Using these calculated forces to analyze the housing, the amount of material needed at the bearing location can be optimized. A safety factor of 2 will applied to the calculation, to insure structural integrity of the housing over the course of its life.

Table 1: Summary of the calculated bearing forces

Bearing	Bearing 1	Bearing 2	Bearing 3	Bearing 4	Bearing 5	Bearing 6
Fx (lbf)	-612	-	-479	-	-	133
Fy (lbf)	1149	985	622	520	826	265

(See Appendix A1.2 Support for details)

The clamping force needed to keep the gearbox sealed is to be calculated. In doing so, the number of screws needed to hold the case together, as well as their locations will be solved for.

Lubrication

Splash lubrication is the most widely used method for lubricating enclosed gearboxes. This is due to the simplicity that it invokes. The simpler the design of the device, the easier and less expensive it is to manufacture. Moreover, according to QTC Gears, it is best chosen as a method of lubrication for gear trains that experience tangential velocities >3 m/s. Our gear train experiences tangential velocities of >30 m/s (*See Appendix B for details*).

Hauff standards for gearbox lubricant is Mobil Lube 629. The gearbox will be designed in accordance to this lubricant selection. Complying to this standard maintains commonality between machinery which makes field maintenance much easier. Furthermore, this is a common lubricant for agricultural equipment. Therefore, the customers (farmers) will have access to the lubricant and most likely will have bought it in bulk. The Mistifier brings back repeat customers, by making the components and the lubricant common to the industry.

Heat Dissipation

Heat generation in a gear box is primarily made up of friction. There is friction in gear meshing, bearing contacts, seal contacts, and in the viscous friction of the lubrication itself. Heat generation is determined by these four factors. It can be calculated by Law of Conservation of Energy. The gearbox will generate heat due to the mechanical inefficiency.

Neugart recommends a gearbox temperature of no greater than 90°C. The cooler the gear box runs, the longer its operational life will be. A reasonable combined heat transfer coefficient of radiation and convection for the design of an enclosed cast iron gear box is 1 $^{kW}/_{m^2}$. This heat transfer coefficient provides a good starting place, however is not accurate in real world applications. The heat transfer coefficient for .375" thick ASTM A 48 Class 30 Gray Cast Iron plate could not be found by a reputable source, so it must be measured through experimentation. The method for determining the heat transfer coefficient is as follows:

1. Heat .375 in thick Class 30 Cast Gray Iron plate to 90°C in the furnace.
2. Pull it out of the furnace and allow it to rest in ambient temperature.
3. Take a reading of the ambient temperature and measure how much temperature the plate uses every minute until the two temperatures match up.
4. The heat loss in the plate over the amount of time it took is the heat transfer rate. This number is then divided by the surface area in contact with the ambient air, and an accurate heat transfer coefficient will arise.

The gearbox housing has been analyzed at the extreme condition ambient temperature of 110°F with no wind. The amount of heat the housing can dissipate while operating at maximum temperature of 90°C under said ambient temperature was determined to be 11.7 HP. This is the equation that was used:

$$\dot{Q} = C_{cr} A_{Housing} \Delta T$$

This number was then compared to the mechanical inefficiency of the gearbox.

$\eta = \frac{Pwr_{out}}{Pwr_{in}} * 100\%$ Note: Typical helical gearboxes tend to be approximately 98% efficient.

Using the conservation of energy formula,

$$Energy_{in} = Energy_{out} + Energy_{lost}$$

The energy lost in the gear box will be turned into heat. This formula was adapted for the housing.

$$\dot{Q}_{dis} = Pwr_{in} - Pwr_{out} = 5.39\ HP < 11.7\ HP = \dot{Q}_{housing}$$

Therefore, the housing will be capable of dissipating all heat due to mechanical inefficiency even in extreme working conditions. The housing is able to dissipate heat to meet the requirement of internal temperature of no greater than 90°C, with a Safety Factor of 2.17; due to the geometry of the part. Moreover, forced air convection and the addition of cooling fins to the housing have been deemed unnecessary.

Production

Pattern Design

Allowable draft angle for cast iron is .125" per ft. The greater the angle of draft, the easier it is to make the mold, but the more issues arise with spatial concerns. The spatial requirements for the housing are not ones that will be difficult to make. Therefore, the draft angle of 2° was chosen based on industry standards. The larger the draft angle, the easier the mold making process is.

Shrinkage rate for cast iron is typically .125" per ft. Therefore, the pattern must be scaled up in size of .125:12 in order to account for the amount the metal will shrink in the mold when it solidifies. *Technology of Metal Casting* suggested the scale up value of 1.9% for all gray cast iron parts.

Sharp angles are problematic in the designing of a cast part. They become weak points. To keep these areas strong and minimize the chance of cracks in the parts, sharp angles must be converted to rounds and fillets. (*Appendix A*)

There are various areas where the casting needs to be machined. Industry standard indicates machined surfaces must be casted .125" larger, so they can be machined to desired finish.

Two patterns in total will be made. The drag negative imprint of the part, the cope positive imprint of the part, and the cope negative imprint of the gating system will all be made in one pattern for the left side of the housing. Typically, the patterns will be mounted on follow boards to fit the squeeze mold pneumatic machine of the foundry.

Cores are necessary in this gearbox, but the fewer cores there are in a mold the less of a change there is more scrap parts due to cores floating and/or shifting. Because iron is such a heavy and dense metal, it builds a lot of inertia when flowing through the mold channels, its momentum can force cores to shift. To account for this one core should be made for the base of the housing and one for the cavity of the housing. If the two cores can be formed into one, then this is the best design.

The scope of this project has changed due to the complexity of the part. The part will no longer be casted at the CWU foundry. Therefore, pattern design in the end will be up to the pattern maker and the foundry that is hired to build the housing.

Mold Design

The two major factors that will lead to scrap castings are shrinkage and porosity. Correct mold design and pouring techniques can prevent these two factors from occurring. Industry standard for ASTM A 48 Class 30 Gray Cast Iron encourages the application of a pressurized gating system with Sprue: Runner: Ingate surface area ratios of 4:8:3. The gating system chosen for this mold was a single, cyclindrical sprue with a corresponding cyclindrical well. Two runners break off of the sprue and make 90° turns, before they run down the length of the part. They each have two ingates to fill the part and end at a vent. The housing is relatively thin walled, therefore it is necessary to gate on both sides of the part, because the part will cool faster than a thick part. The vents insure that the metal flows nicely through the system and unwanted gasses have a means to escape.

The choke area of a pressurized gating system is found at the ingates. This is the formula used to determine the total surface area of the choke:

$$a = \frac{W}{\rho k t \sqrt{2gh}};$$

where a = total surface area of the choke; W = weight of the casting; ρ = density of the metal being poured; k = the coefficient friction of the sprue shape; t = the estimated pouring time; g = gravity; h = effective head.

After solving for the surface area of the choke, the dimensions of the ingates, runners, sprue, and sprue well can all be determined. The surface area of the choke was determined to be $.607\ in^2$; with this information, the following table of dimensions of the gating system were found:

Table 2: Mold Design

Ingates		**Sprue**	**Runners**		**Sprue Well**		
Height	Width	Diameter	Thickness	Width	Diameter	$Depth_{Cope}$	$Depth_{Drag}$
.443 in	.885 in	.816 in	.723 in	.361	1.223 in	1.084 in	.361 in

The mold, including the casting, will be assembled in SolidWorks and imported to SolidCast for evaluation. Shrinkage and porosity evaluations being the most important. Depending on the SolidCast evaluation, it will be determined if risers are necessary.

Sand Control

Sand control will be vital to the mold making process. A great batch of sand makes a great mold. New sand will be used to face the mold, in order to insure the best surface finish. Old sand will be used as the backing sand.

All sand water content will be tested using the compression testers found in the foundry. The compressed sand specimen must have a water content of 3-5%.

Fluidity

The best pouring temperature for cast iron is in the range of 2525°F - 2642°F. The housing molds will be poured at 2600°F. Due to rapid cooling as the molten metal hits the cold green sand mold, the casting is estimated to take metal at 2550°F. This is accounting for 50°F lost in heat dissipation by the green sand mold, which is the estimated number that SolidCast suggests for this application.

Machining

The casting must be machined before it is a finished part. The order by which the casting is machined is vital to the tolerance of the part. Because of the tight tolerances and somewhat complicated geometry this order must be followed.

1. The bottom of the base will be milled to a flat surface. This will serve as a datum.
2. The face of the casting will be milled perpendicular to the base and to a flatness tolerance of ±.005".
3. The holes for the 5/16" clamping screws are drilled and tapped in locations predetermined in the drawing.
4. The plate will then be bolted securely to the housing and the shaft holes will be drilled and bored.
5. The location of the input/output hole will be measured off the bottom surface of the base of the housing. It will be drilled and bored to the specifications of the drawings.
6. The output hole location will be measured off of the input/output hole location to the specified center distance and its height will be taken from the same origin as the other bore.
7. Any additional drilling and taping for the fill hole and weep hole will be done subsequently.

Critical Failure and Safety Factors

The gearbox can critically fail in two ways:

1. If the forces at the bearings are greater than the shear strength of the housing then the housing will crack. This force can be amplified if the tolerances between the bearing outer races and the housing are accounted for. If the interference fit were too tight, when the bearing expands after being shrink fit into the housing, it can crack the housing.
2. If the gearbox operates at a temperature higher than 165°F. The oil will be the first to fail; it will burn up and lose its lubricating properties. Then, the bearings will wear out. When the bearings wear out, the forces at the gears will not be supported. Chatter will occur, and then the gear teeth will shear.

If the force fits between bearing and housing are not toleranced correctly, when the bearing expands it can crack the housing. Especially in the case of using ASTM A Class 30 Cast Iron, because it is a brittle material. For this reason, careful tolerancing and Neil's own personal expertise in bearing fits have been used to determine the fits of the bearings in the housing. Furthermore, the supporting ability of the housing at the bearings has been analyzed.

Safety factor for the supporting properties of the housing is 6.5 at its weakest point. The safety factor is high, because the gearbox needs to be strong enough to survive an impulse force of the same magnitude. An impulse would occur at the bearing in the case of a farmer dropping the clutch on the tractor. This high safety factor is a practice of H.F. Hauff Company after issues arose in past production models.

The benchmark, Bima box, failed due to maintenance issues regarding its oil. Similar to the gearbox operating too hot, the oil burned up. Then, the bearings wore out. Then, the gear teeth sheared off. For this reason, the cavity of the gearbox has been expanded to allow for greater oil capacity. This will lead to greater heat dissipation power of the box, lower operating temperature, and a longer time frame between scheduled oil changes and maintenance operations.

Device Shape

The gearbox housing must be shaped in such a way that the gears and shafts are supported and can function. There cannot be interference between the gearbox and the gears themselves. The gear train was analyzed and calculations for size and shape of the housing were made. A clearance of .375 in at the nearest locations was accounted for in the geometry.

The device shape is held in parameters due to function, ease of assembly, conformity to other components, and overall simplicity.

Device Assembly

The housing and the plate will be machined together to insure hole concentricity. Then, the gear train assembly with all bearings and seals will be assembled inside the housing. The housing will be closed together and clamped tight, using 5/16" bolts. It will be sealed with RTV sealant. The spy hole, drain plug, and fill/vent will be installed. It can then be filled with oil. The gearbox will be mounted to the trailer with 5/8" bolts. It then be connected to the components; the tractor PTO and the fans. Once it has been properly incorporated into the Victair Mistifer, testing and evaluation can occur.

Tolerances

The bore center distances and housing to plate concentricity are the most important geometries of the part. They will hold tolerances of $\pm$ .001”. The mating surface and the bottom of the base must be perpendicular to $\pm$ .001” and flat to $\pm$ .001”. The bearing seats and seal seats will hold the tightest tolerances of the housing. The bearings will be shrink fit into the housing with a tolerance classification of J6 (p.2385 MHB). Therefore, the clearance between the bearing outer race and the housing is -.0002” → +.0006”. The seals must keep all oil in and dirt out. Seal manufacturers give a recommended housing tolerance for each of their seals. These recommended tolerances will be used to tolerance the bore of the housing.

Technical Risk Analysis

Technical risk will be analyzed three-fold: production, maintenance, and environmental impact.

Cost is the number one concern in production and manufacturing. It is a risk that this device can be built at a cost effective price for the application. Neil Hauff will be influential in determining how certain aspects of the device can be manufactured in order to maintain lean manufacturing. Even if the device works flawlessly, if it costs too much to manufacture it will not be used in production.

The gearbox must be easily maintained. Certain aspects such as; the accessibility of the drain plug and fill hole, location and accessibility of the clamping screws, and the use of RTV as a sealant instead of using a gasket are all factors in that were accounted for in design, to make maintenance of the gearbox in the field easier.

The environmental impact of the gearbox comes from the imbedded energy it took to manufacture it, and the possible impacts it may have on its environment in its life time. All of the materials used to manufacture and build the gearbox are recyclables, with the exception of the seals and RTV sealant. The gearbox is sealed to prevent oil spills from occurring in the field. The clamping force necessary to sufficiently and securely seal against the housing has been analyzed, so that spills do not occur; such spills could be detrimental to the environment due to its agricultural application.

METHODS AND CONSTRUCTION

Description

Lean manufacturing is of utmost importance for the production of the gearbox. With that in mind, the idea to cast this part as a single part has developed. A fabricated plate and tube weldment will serve as the right side of the housing to seal it.

However, the prototype housing will be fabricated out of .375" AISI 1010 Steel Plate. The reason for doing so is to ensure that the product functions efficiently and change any issues that may be found before the money is put up to put the housing into production casting. The steel housing will be designed in a very similar manner to how the actual casting will look. Doing so will allow the fabricated housing to most closely emulate the cast housing for testing and evaluation.

Drawing Tree

The drawing tree ends at the finished product, the Gearbox Housing. It is comprised of two parts, the Housing and the Plate. The housing has a casted drawing and a weldment drawing. The right plate is a fabricated weldment that has two major components; the right boss and the plate.

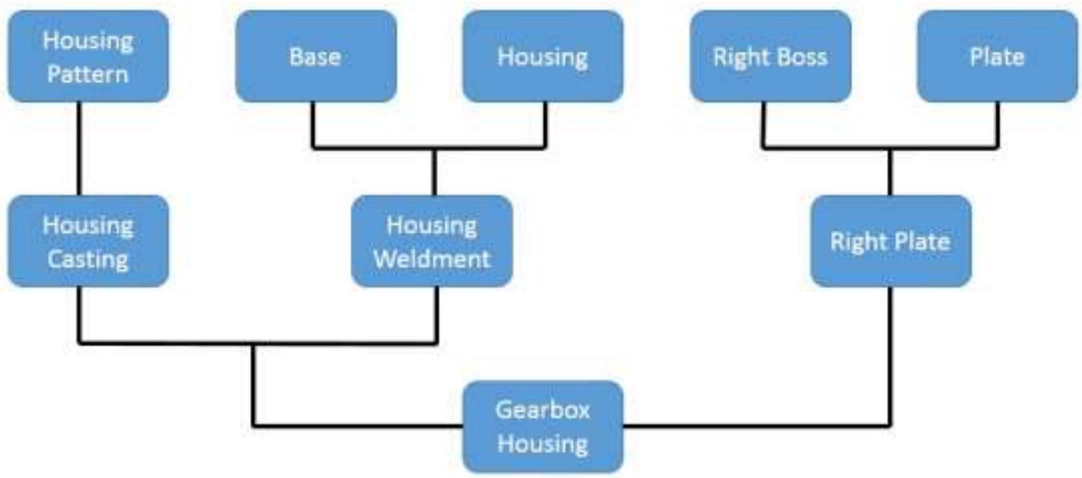

Fig. 4 – Drawing Tree

Manufacturing Issues

Machining of the part will be the most difficult task due to its unique geometry and tight tolerances. The sequence by which the various sides of the housing get machined must be followed to a tee, or the parts dimensions will be off and issues in assembly will arise.

Discussion of Assembly

It is vital to assembly that all of the machining is accurate. The assembly has a sequence, so that all the components fit correctly and function. The assembly procedure of the gearbox will go as follows:

1. The upper shaft will be assembled.
   a. The bearings will be shrunk fit to the shaft.
   b. Gear 3 will be shrunk fit to the end of the shaft and a No. 8 nut will be screwed on to it using Loctite.
2. As a pack, the upper shaft will be installed into the housing.
   a. The housing will be heated and the upper shaft pack will be chilled.
   b. The upper shaft will be slid into the bore of the housing from right to left, until the first bearing is hanging out of the housing. The back snap ring will be installed. The shaft will be slid back into the housing against the snap ring and a second snap ring will be installed in front of the bearing.
   c. The seal runner and seal will be added next.
3. The input shaft will be installed into the housing.
   a. Gear 1 will be assembled to the input shaft by a Tollok keyless hub. It will be assembled at a certain height with the aid of an assembly stand that must be fabricated.
   b. A sleeve will be shrunk fit to the shaft. And then a bearing on to the sleeve. The input shaft pack will then be frozen and slid into a heated housing.
4. The hollow shaft will be installed into the plate.
   a. It will be installed in the same manner by which the upper shaft was installed to the housing.
5. Finally, the hollow shaft and plate pack will be installed over the input shaft and clamped on to the housing.

TESTING AND EVALUATION

Introduction

The gearbox housing will be tested in multiple stages of its development. Virtual testing to determine weight, size, geometric shape and fits, and so can be performed on SolidWorks.

Testing of the complete assembly after all production and assembly has been completed will occur to ensure that the product will not fail when out in the field. This will be an extensive test of the gearboxes ability to dissipate heat.

Method

MOLD:

- SolidCast Simulation
  - Material Density Inspection (See Appendix A – Analysis: SolidCast
  - Microporosity Inspection
- Sand compression test
  - 3-5% Water Content

FINAL ASSEMBLY:

- Gearbox will be mounted to a board at an appropriate height and fitted to a PTO from a tractor, as it would in typical use.
  - 1st test would test for proper rpm on the output shafts. And overall device operation ie leaks, gear mesh, bearing squeak, etc.
  - 2nd test would incorporate the fans to induce a load on the gearbox and the operation will be evaluated.

Test Procedure

Sand Compression Test – 3-5% Water Content

Chart will determine what height the sand needs to be at in order to be within 3-5% water content spec. This height measurement will be compared to the testing height measurement to determine if the sand falls into tolerance or not.

Final Assembly Test 1

A timing mark on the input and output shafts will be made and the gearbox will be run. A timing gun will be placed on the input and output shafts. The results will be checked against requirements to determine success or failure.

Auditory and visual checks will also be performed to maintain the gearbox is working correctly.

Final Assembly Test 2

Fans will be mounted to the shafts and the gearbox will be run under load. The temperature of the gearbox from start up to operation for one hour will be measured. The inside of the gearbox cannot exceed 90C.

Final Assembly Test 3

Gearbox will run non-stop for 48 hours with a fluke temperature monitor hooked to it. The ambient temperature as well as the temperature of the box will be recorded. Subsequently the data can be used to generate a temperature over time graph as well as a temperature over rpm graph.

Deliverables

Deliverables for testing are the evaluation reports. The evaluation reports will directly correspond to satisfaction of requirements, as well as any visual issues, auditory issues, or any other issues that may arise.

SolidCast

Microporosity was found in the base of the gearbox of simulated pour for Mold Design 1. Material density issues and porosity were found in the machining areas of the bearing supports. These are both serious issues that must be resolved through mold design. The most common reasons for porosity to occur is that the metal is too cold when it is filling the section, and there is not enough flow to fill the section.

The microporosity in the base can be fixed by either putting a chill in the bottom of the mold where microporosity was present, or just thickening up that section of the casting. I would opt to thicken the section of the casting, because weight is not a critical requirement on this casting and the pattern design has not been finalized.

The material density and bigger sections of porosity are a much bigger concern. But they too can be fixed with a couple solutions. The SolidCast image shows an interesting feature from the pour simulation. Note the porosity located in the side runner on the right side of the mold. The same side that the runner was feeding into has much less porosity than the other. What this shows is that the runner was actually acting as a riser and metal was being sucked out of it and into the casting. This is important feedback, because it gives support to the hypothesis that a blind riser is needed in line with each of the four ingates. This solution should solve the problem.

These were images of Mold Design 1 and the design of the casting has now changed again. A note that risers on the ingates has been made, but no further calculations need to be made until the final design is completed.

PROPOSED BUDGET

Materials and Parts Suppliers

The AISI 1020 plate, rounds and mechanical tubing will all be supplied by the Hauff Co. material supplier, Pacific Steel and Recycling. This raw material will be used to produce the prototype gearbox housing. The material will be bought in bulk, therefore the price of material will be listed in the budget by $/lb.

The screws to secure the top housing to the bottom housing can be supplied by Grainger, as they are a common fastener.

Labor

Labor and assembly time has the greatest potential for savings in the production of the gearbox. Hauff production shop time is estimated at $85.00/hr. This estimation includes machinery, utilities, labor and other overhead. The production and assembly time for a production gearbox is estimated to be 8 hours in total. Meaning that the cost of labor for the production gearbox will equate to $680.00.

The cost of labor for production and assembly of the existing 19 components that perform the job of what the new gearbox will do equates to an estimated 24 hours. That means the new production gearbox will save nearly 67% in labor costs.

Total Project Cost Estimate

The estimated total project cost of materials is estimated to be $4,509.93. The total cost increases to $5,189.93 with the inclusion of the cost of labor. Details can be found in Appendix D.

Funding Source(s)

H.F. Hauff will supply all funding for the project.

GGB Bearings has kindly donated the plain surface bearings necessary for the prototype.

PROPOSED SCHEDULE

The proposed schedule will act as a good guideline to keep the project focused and on track. It is also an easy way to quickly indicate if the project has fallen behind. The proposed schedule can be found in Appendix E.

The proposed schedule has estimated that 262 hours will be needed in order to complete this project as a team from cradle to grave. Cumulatively, the project design and analysis has taken 151.9 hours as of 2.9.2015. The drawings for outsourced parts were sent out this week. The project has eaten up more than half of the estimated time given for project completion. Which indicates that the project is behind schedule and will ultimately take more time to finish than was originally estimated.

Although the design and analysis portion of the project are taking longer than anticipated, the project build time has the potential to be quicker than estimated. Originally, it was thought that much of the manufacturing and fabrication was going to be performed by the team members. However, it has been determined that the Hauff Company's machinists and fabricators will be building the project parts to the tolerances and dimensions displayed in the drawings.

PROJECT MANAGEMENT

Human Resources

Teammates Ricky Skinner and Casey McFarlen have been influential in getting goals accomplished, brainstorming, communicated, and really just getting the job done. It is a huge asset to have team members for a project of this magnitude.

Class peers have also been very helpful, especially Chris Nichols who provided the basic skills needed to familiarize with SolidCast.

Neil Hauff, the boss, has been very helpful and patient as the device has been in the design stage. He will be increasingly influential in the manufacturing stages, as most of the work will be performed at his shop.

Physical Resources

H.F. Hauff Company, Inc. manufacturing building, machining shop, and more will be the biggest asset to the building stage of the gearbox.

The CWU machine shop will be influential in any quick and easy machining that needs to get done.

Soft Resources

SolidWorks has been incredibly helpful in the design stage. It is amazing that engineers once drew everything out by hand.

SolidCast has proven to be incredibly helpful in the mold design, addition of risers, and porosity analysis. It will continue to be used as the design progresses.

Financial Resources

H.F. Hauff Inc. has provided the team with an incredibly learning experience to design and develop this gearbox housing. They will provide financial backing for the prototype production.

DISCUSSION

Design Evolution

The design started as a simple box to house the gears. It was meant to be symmetrical, so that only one pattern would have to be made. However, it could not be done. As the gear train and assembly became more complicated, so too did the housing. The project really went full circle from very simple and basic, to overly complicated and back again to simple and basic.

The design of the housing drastically changed towards the end of the quarter as further requirements were added to the housing design. The goal of the housing was to fit into the orchard sprayer original assembly without alteration. The follow items need to be incorporated into the housing for the final design to be signed off: collars to support the fans, a mounting base, a mounting tab for the existing handle mechanism to rotate the fans, as well as the existing drain plug, fill hole, and spy glass would need to be incorporated. The dimensions for said design alterations have been provided by Hauff.

After 5 total designs, the housing design is complete. Drawings have been submitted to Neil to be signed off.

Project Risk analysis

Time has been a large risk factor in producing a successful housing. The addition of new requirements and continuing to redesign the gearbox inners have led a lack of time.

This project has been a “learn as you go” type of project. Having three inexperienced engineers on the project has led to wasted time. Also, the fact that the engineers were assigned to separate components of the gearbox has led to more problems and inefficiencies than initially anticipated. Each engineer went out on their own to accomplish the challenging task that they were assigned. After failures, the team came together and worked together to complete each step in the design process of the gearbox, Neil Hauff mentoring them through it. Had they had a better idea of the obstacles they faced before they headed into them, they would have saved valuable time, energy and headaches.

Cost is of course the greatest factor, if the housing does not cost less than the Bima Box, then the project has failed.

Successful

The project has already been a success. The shear amount of work, research and calculations that have had to be performed on this project has led to a massive increase in engineering knowledge. It has been a difficult and time consuming challenge, but the knowledge and lessons learned shall hold weight for many future years in the engineering industry.

The calculations and diligent design work will pay off as the project is tested and evaluated and eventually runs into production.

Next Phase

The prototype gearbox will be manufactured and assembled in the H.F. Hauff Company Machine shop. In the spring semester it will be ready for testing and evaluation.

The gearbox was tested and the design was proven. Although there are a few revisions that need to be addressed before production can begin. Also the casting tooling will have to be ordered and jobbed out.

CONCLUSION

H.F. Hauff Inc. builds the Victair Mistifier Orchard and Vineyard Sprayer. The company continually attempts to optimize the production process and lean manufacturing without losing functionality of the equipment. The engineering team was hired to revamp the gearing that operates the fans, which blow the chemical/water mixture on to the crops. The job was to take 19 functioning parts and incorporate them into one gearbox that will be mounted into the existing position where a gearbox is currently mounted, between the fans. This gearbox will increase production efficiency greatly. It will save time in the manufacturing of fewer parts as well as save time in the assembly of the sprayer system.

The scope of this proposal is to design and build a metal cast housing that will encase the gears, seals, bearings and shafts of the gear train. The geometry of the housing must allow a minimum clearance of .375" for the inside gears, as well as dissipate the heat due to mechanical inefficiencies of the gear train so that the inside of the housing does not exceed a temperature of 90C. The geometry must also fit the current machine set up. The existing tab must be mounted to the top of the housing, as it plays a major role in the handle mechanism function and mounting. The existing collars must be mounted to the shaft outputs to support the fans on either side of the housing. The original material, ASTM class 30 Cast Gray Iron will be used, as it is already proven to work in the original design.

The housing is predicted to support the fans, gear train, and handle mechanism. Testing of actual performance will indicate if the gearbox performs in a sufficient manner.

The housing is only one component of the gearbox. The gears, bearings, seals, shafts and other minor components have also been selected and drawn by the team. Said drawings of the other gearbox components and the assembly drawings are not included in this proposal, but will be included in the final report and presentation.

The gearbox was an incredible success and will make the Victair Mistifier a more sustainable and better overall sprayer.

ACKNOWLEDGEMENTS

Acknowledgements of gratitude go out to the follow people and organizations, who have seen this project to culmination:

- Team members Casey McFarlen and Ricky Skinner, for the dedication and determination that has been necessary in this challenging project.
- Neil Hauff, for his mentorship throughout the process.
- Dean Hauff, for the funding of the project.
- H.F. Hauff Company, for its investment into education and the financial backing.
  - Pat, Shop Manager
  - Jesus, Machinist
  - Martín, Welder and Fabricator
- Dr. Johnson, for his relentless efforts to see the team “do more.”
- Prof. Pringle, for his personal hours invested in helping clear up critical project issues.
- Mr. Ted Bramble, for his expertise in manufacturing and ANSI Y14.5 standard of drawings.

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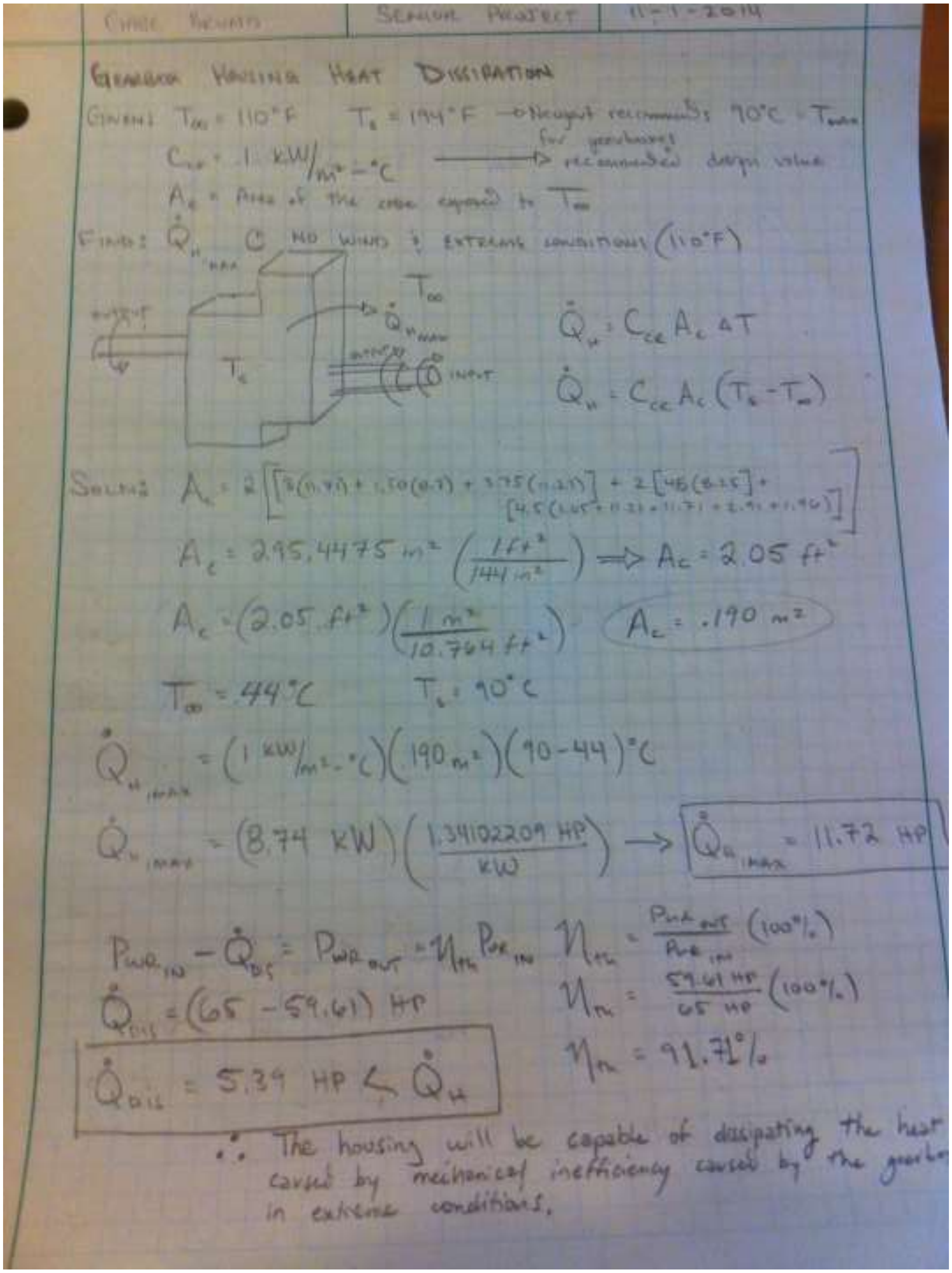
APPENDIX A – Analyses

A.1 - Function

A.1.1 - Heat Dissipation

Design 1



Chase Knights | Senior Project | 11-1-2014

Gearbox Housing Heat Dissipation

Given: $T_\infty = 110°F$ $T_s = 194°F$ → Neugart recommends 90°C = T_{max} for gearboxes

$C_{ce} = 1\ kW/m^2-°C$ → recommended design value

A_c = Area of the case exposed to T_∞

Find: $\dot{Q}_{H_{MAX}}$ @ no wind & extreme conditions (110°F)

T_∞ $\dot{Q}_{H_{MAX}}$ T_s output input

$\dot{Q}_H = C_{ce} A_c \Delta T$

$\dot{Q}_H = C_{ce} A_c (T_s - T_\infty)$

Soln: $A_c = 2\left[\left[3(11.71) + 1.50(8.7) + 3.75(11.21)\right] + 2\left[4.6(8.25)\right] + \left[4.5(2.05 + 11.21 + 11.71 + 2.91 + 1.96)\right]\right]$

$A_c = 295.4475\ in^2 \left(\frac{1\ ft^2}{144\ in^2}\right) \Rightarrow A_c = 2.05\ ft^2$

$A_c = (2.05\ ft^2)\left(\frac{1\ m^2}{10.764\ ft^2}\right)$ $A_c = .190\ m^2$

$T_\infty = 44°C$ $T_s = 90°C$

$\dot{Q}_{H_{MAX}} = (1\ kW/m^2 \cdot °C)(.190\ m^2)(90-44)°C$

$\dot{Q}_{H_{MAX}} = (8.74\ kW)\left(\frac{1.34102209\ HP}{kW}\right) \rightarrow \boxed{\dot{Q}_{H_{MAX}} = 11.72\ HP}$

$P_{WR_{IN}} - \dot{Q}_{DIS} = P_{WR_{OUT}} = \eta_{TR} P_{WR_{IN}}$ $\eta_{TR} = \frac{P_{WR_{OUT}}}{P_{WR_{IN}}}(100\%)$

$\dot{Q}_{DIS} = (65 - 59.61)\ HP$ $\eta_{TR} = \frac{59.61\ HP}{65\ HP}(100\%)$

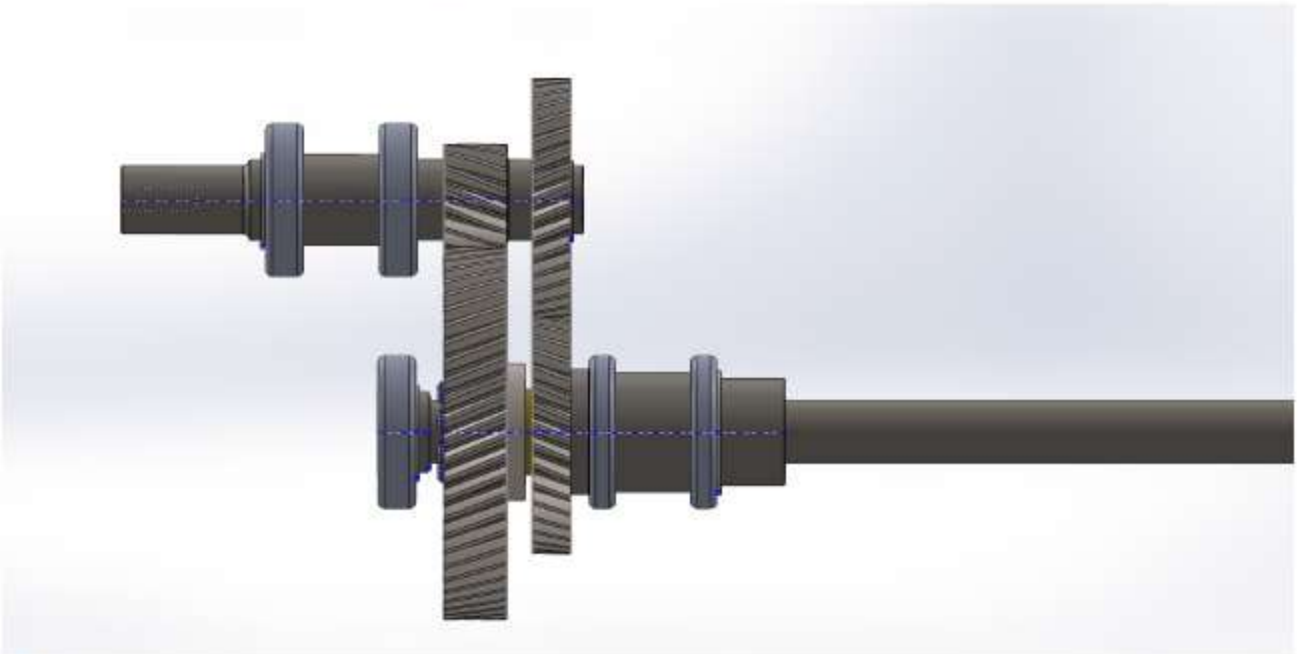
$\boxed{\dot{Q}_{DIS} = 5.39\ HP < \dot{Q}_H}$ $\eta_{TR} = 91.71\%$

∴ The housing will be capable of dissipating the heat caused by mechanical inefficiency caused by the gearbox in extreme conditions.

A.1.2 – Bearing Calculations

Input Shaft Analysis

Top View



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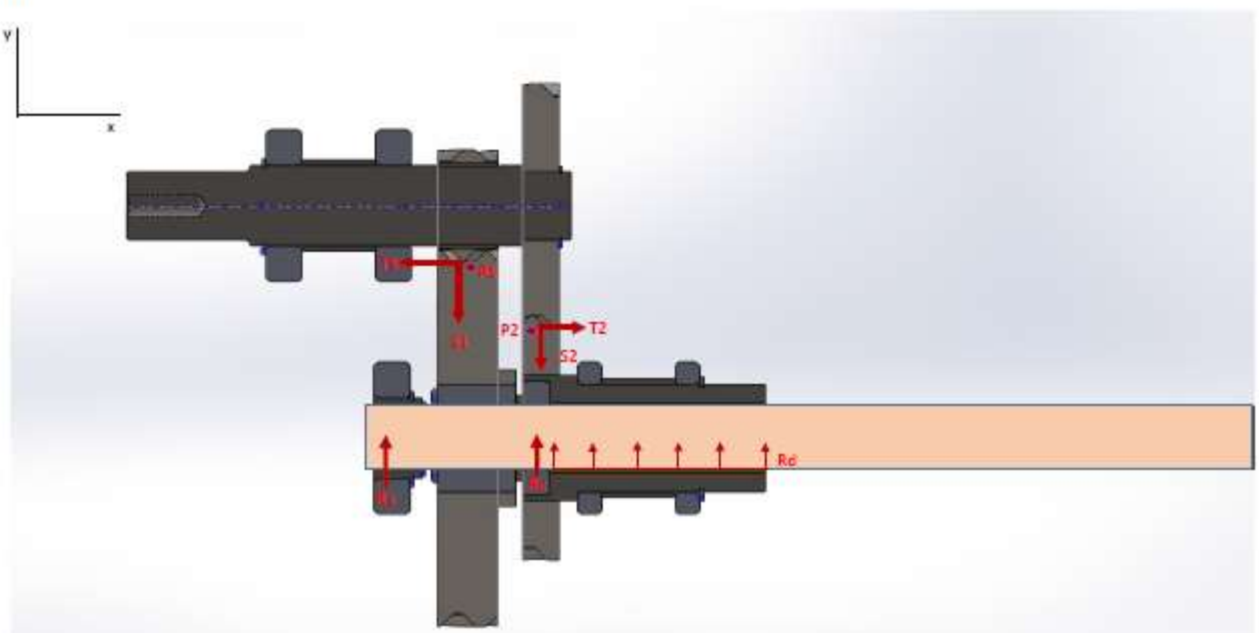
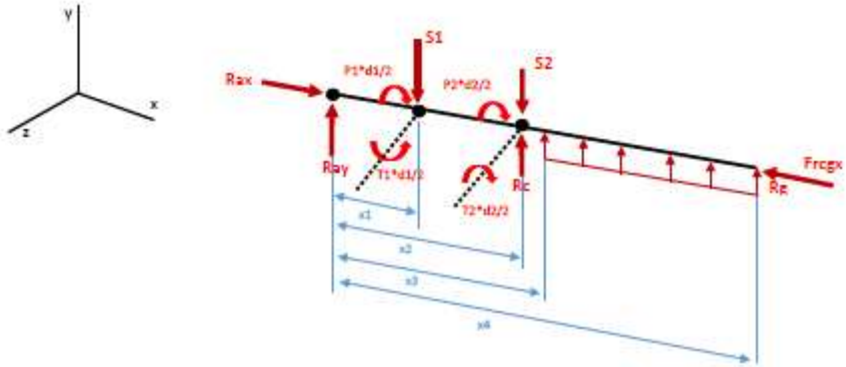
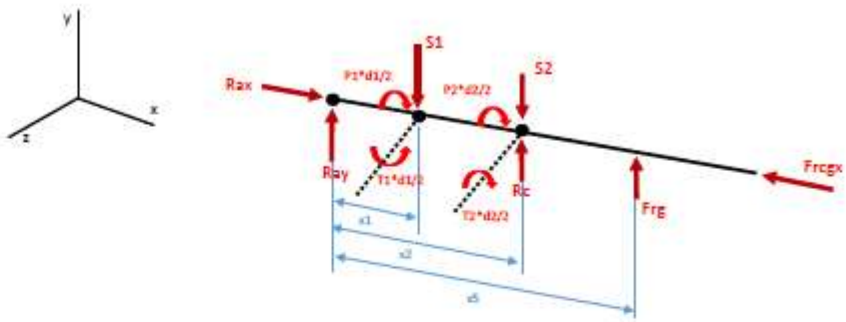
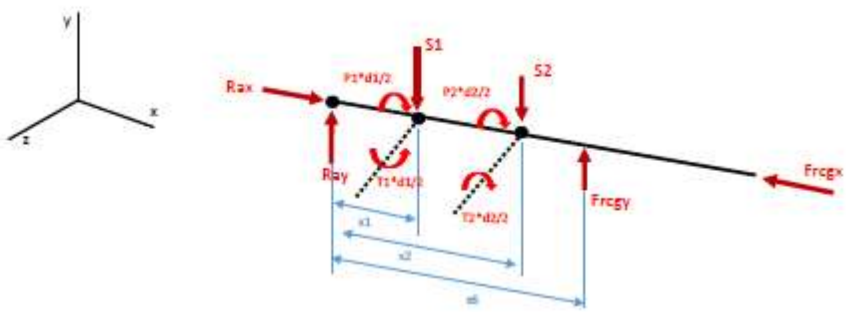
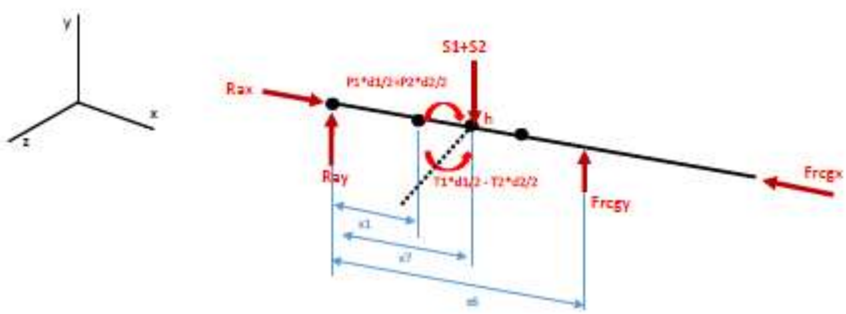


Load Diagrams









Given:	P1	=	1313 lbf
	S1	=	-527 lbf
	T1	=	-612 lbf
	d1	=	8 in
	P2	=	286 lbf
	S2	=	-115 lbf
	T2	=	133 lbf
	d2	=	5.103 in
	P3	=	1599 lbf
	S3	=	-642 lbf
	T3	=	-479 lbf
	x1	=	1.56 in
	x2	=	3.05 in
	x3	=	3.24 in
	x4	=	10.44 in
	x5	=	6.836 in
	x6	=	4.9435 in
	x7	=	2.306 in
Find:	Pa	=	853.1127 lbf
	Sa	=	-342.526 lbf
	Ua	=	-426.55 lbf
	Ray	=	1148.599 lbf
	Rax	=	-612 lbf
	Pcg	=	745.8873 lbf
	Scg	=	-299.474 lbf
	Ucg	=	-426.55 lbf
	Frcgy	=	1040.894 lbf
	Frcgx	=	133 lbf
	Rcy	=	520.4468 lbf
	Frgy	=	520.4468 lbf
	Rgy	=	72.28428 lbf/in

Load classification		Bearing A	Bearing B
Radial load	From P_1	$P_A=\frac{b}{a+b}P_1$ ⊗	$P_B=\frac{a}{a+b}P_1$ ⊗
	From S_1	$S_A=\frac{b}{a+b}S_1$ ↑	$S_B=\frac{a}{a+b}S_1$ ↑
	From T_1	$U_A=\frac{d_{p1}/2}{a+b}T_1$ ↑	$U_B=\frac{d_{p1}/2}{a+b}T_1$ ↓
Combined radial load		$F_{rA}=\sqrt{P_A^2+(S_A+U_A)^2}$	$F_{rB}=\sqrt{P_B^2+(S_B-U_B)^2}$
Axial load		$F_a=T_1$ ←	

Load direction is shown referring to left side of Fig. 3.

Bearing Analysis:

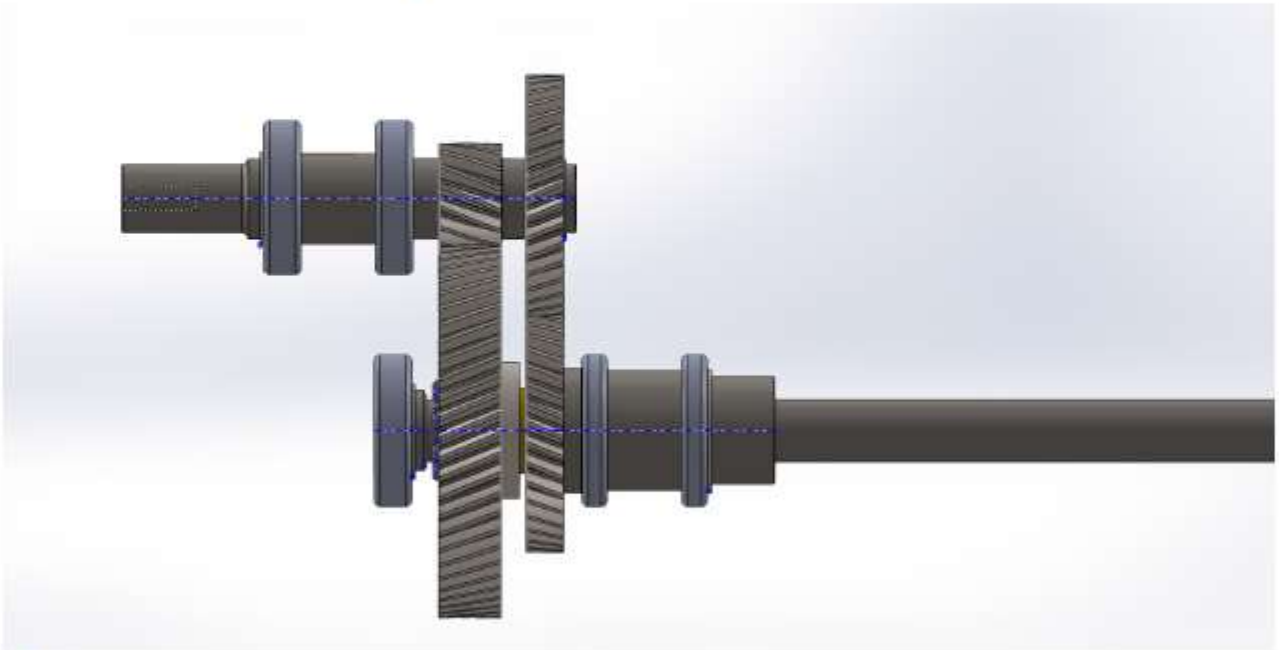
Given:	Pda	=	1301.469 lbf
	Pdc	=	520.4468 lbf
	rpma	=	540 rpm
	rpmc	=	1418 rpm
	Life	=	4500.00 hrs
	ka	=	3.00
	kc	=	3.20
Find:	Lda	=	145.8 rev*10^6
	Ldc	=	382.86 rev*10^6
Dynamic	Ca	=	6849.935 lbf
Calculated	Cc	=	3338.692 lbf
Static	Coa	=	2602.939 lbf
Calculated	Coc	=	1040.894 lbf

Bearing Selection

209K	Dynamic	Ca	=	8160 lbf
	Static	Coa	=	4600 lbf
R22	Dynamic	Cc	=	3590 lbf
	Static	Coc	=	2320 lbf

Hollow Shaft Analysis

Top View



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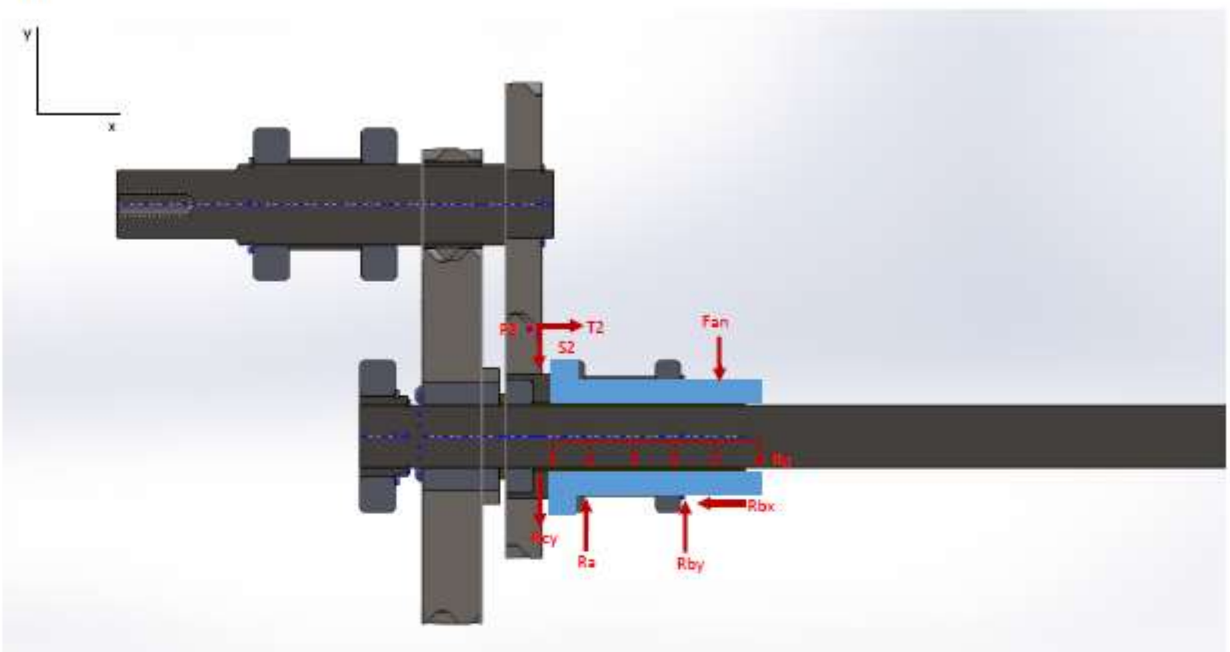
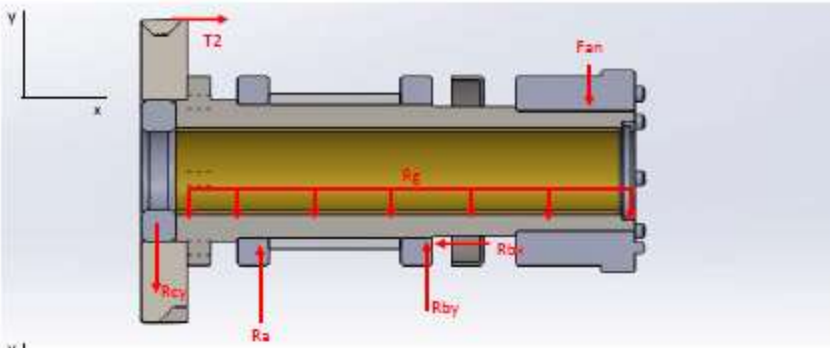
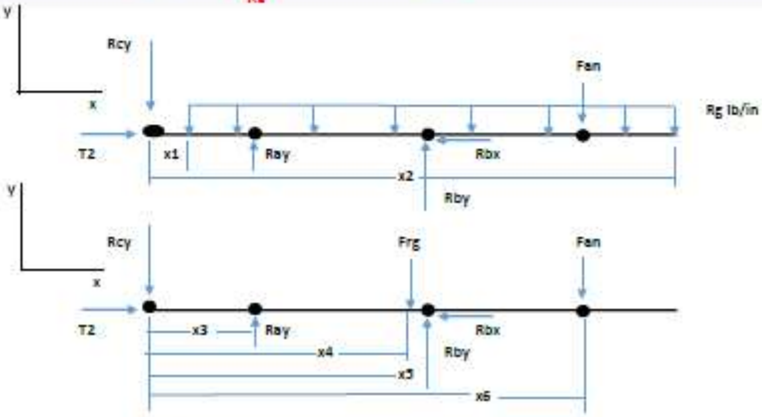






Given:	x1	=	0.28 in
	x2	=	7.48 in
	x3	=	1.53 in
	x4	=	3.88 in
	x5	=	4.18 in
	x6	=	7.05 in
	T2	=	133 lbf
	Rg	=	72.28 lbf/in
	Frg	=	520.45 lbf
	Rcy	=	520.45 lbf
	Fan	=	50 lbf
Find:	Rby	=	265.1958 lbf
	Rbx	=	133 lbf
	Ray	=	825.7042 lbf

Bearing Analysis

Trial 1

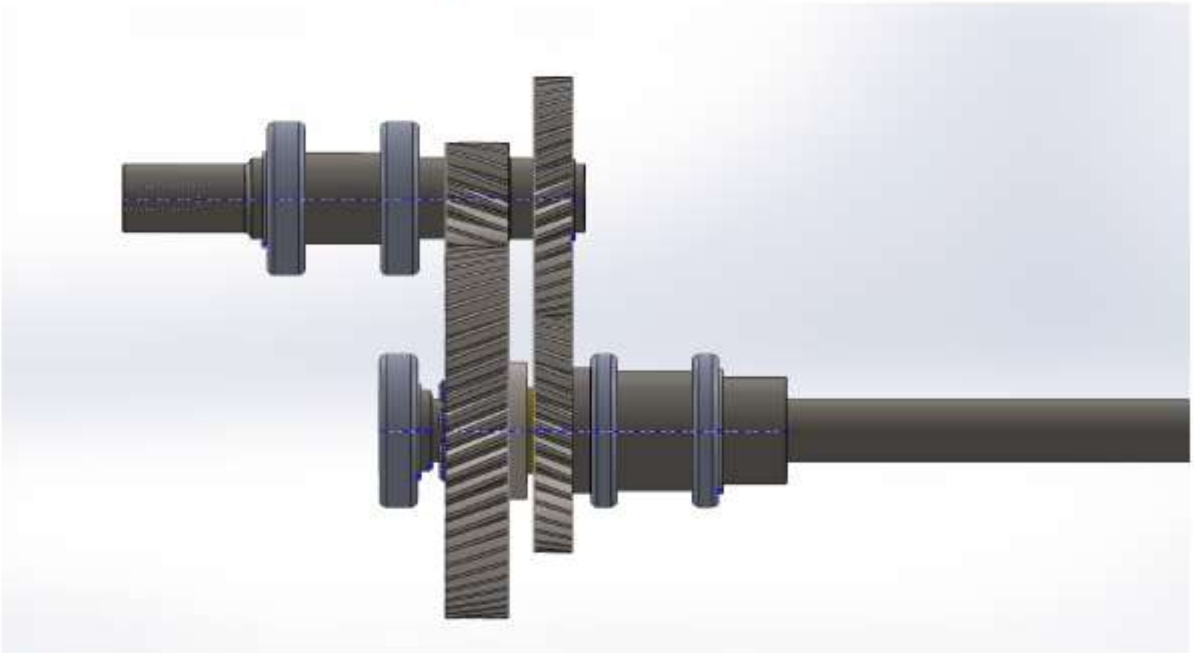
Given:	Pda	=	825.7042 lbf
	Pdb	=	296.68 lbf
	rpm	=	1958 rpm
	Life	=	4500 hrs
	k	=	3
Find:	Ld	=	528.66 rev 10^6
Dynamic	Ca	=	6676.517 lbf
Calculated	Cb	=	2398.893 lbf
Static	Coa	=	1651.408 lbf
Calculated	Cob	=	593.356 lbf

Bearing Selection

NA4912	Dynamic	Ca	=	14,837 lbf
	Static	Coa	=	25,628 lbf
61912	Dynamic	Cb	=	3,710 lbf
	Static	Cob	=	2,700 lbf

Upper Shaft Analysis

Top View



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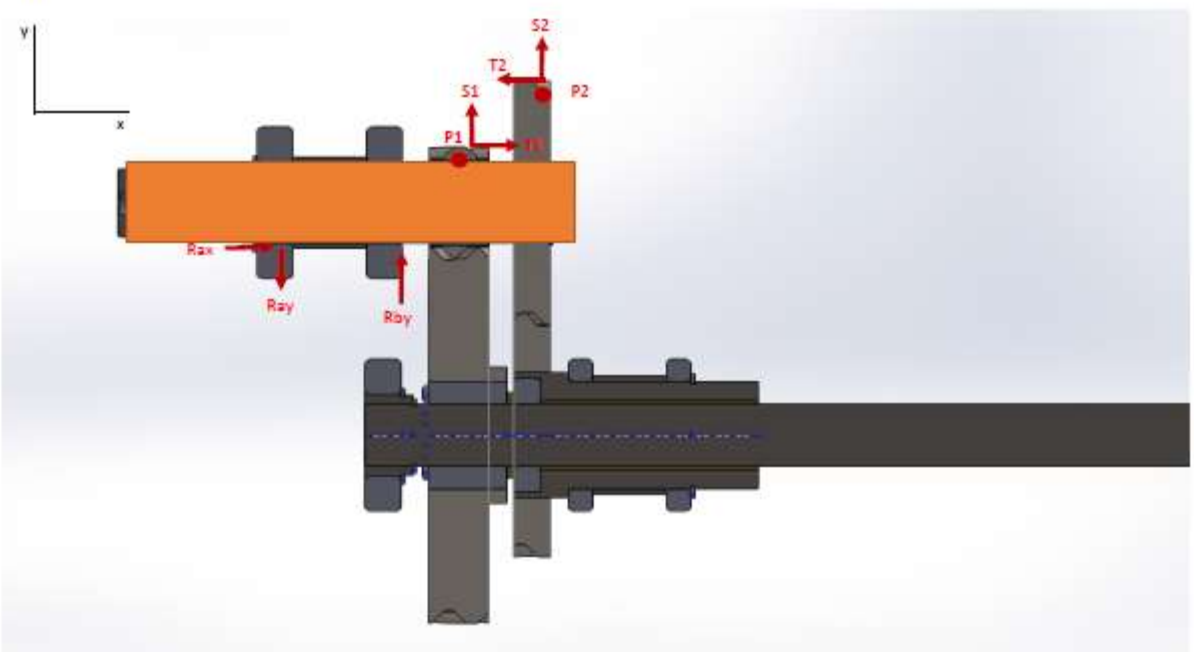
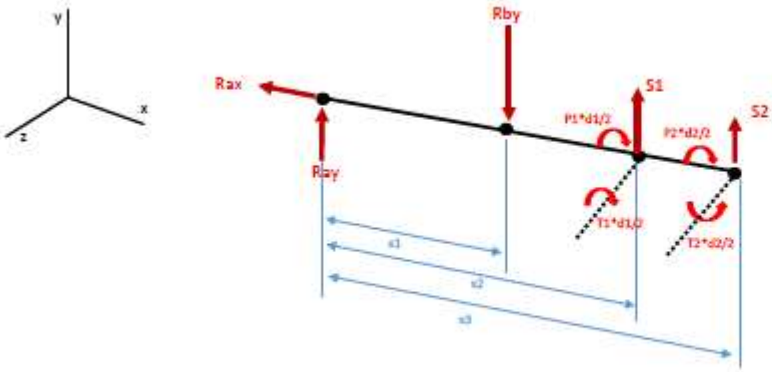
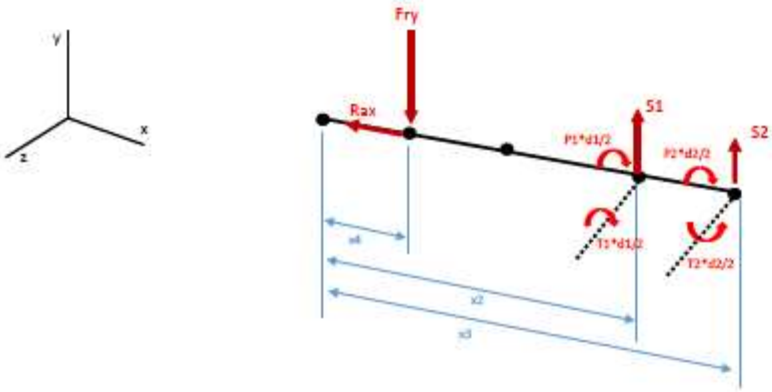
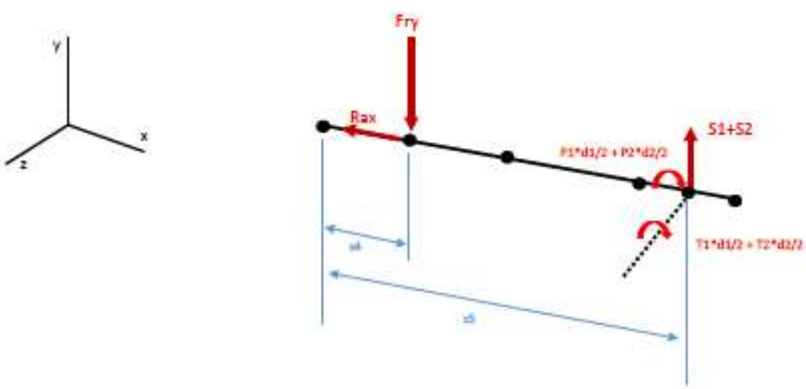


Load Diagrams







Statics Analysis:

Given:	P1	=	1313 lbf
	S1	=	527 lbf
	T1	=	612 lbf
	d1	=	2.207 in
	P2	=	286 lbf
	S2	=	115 lbf
	T2	=	-133 lbf
	d2	=	5.103 in
	P3	=	1599 lbf
	S3	=	642 lbf
	T3	=	479 lbf
	x1	=	3.592 in
	x2	=	5.111 in
	x3	=	6.611 in
	x4	=	1.80 in
	x5	=	5.861 in

Find:	Pfr	=	1599 lbf
	Sfr	=	642 lbf
	Ufr	=	-802.957 lbf
	Fry	=	1607.081 lbf
	Frx	=	-479 lbf
	Ray	=	622.1577 lbf
	Rax	=	-479 lbf
	Rby	=	984.923 lbf

Load classification		Bearing A		Bearing B	
Radial load	From P_1	$P_A=\frac{b}{a+b}P_1$	⊗	$P_B=\frac{a}{a+b}P_1$	⊗
	From S_1	$S_A=\frac{b}{a+b}S_1$	⬆	$S_B=\frac{a}{a+b}S_1$	⬆
	From T_1	$U_A=\frac{d_{p1}/2}{a+b}T_1$	⬆	$U_B=\frac{d_{p1}/2}{a+b}T_1$	⬇
Combined radial load		$F_A=\sqrt{P_A^2+(S_A+U_A)^2}$		$F_B=\sqrt{P_B^2+(S_B-U_B)^2}$	
Axial load		$F_a=T_1$ ⬅			

Load direction is shown referring to left side of Fig. 3.

Bearing Analysis:

Given:	Pda	=	785.1886 lbf
	Pdb	=	984.923 lbf
	rpma	=	1958 rpm
	Life	=	4500.00 hrs
	ka	=	3.00

Find:	Ld	=	528.66 rev*10^6
Dynamic	Ca	=	6348.914 lbf
Calculated	Cb	=	7963.936 lbf
Static	Coa	=	1570.377 lbf
Calculated	Cob	=	1969.846 lbf

Bearing Selection

209K	Dynamic	Ca	=	8160 lbf
	Static	Coa	=	4600 lbf
209K	Dynamic	Cb	=	8160 lbf
	Static	Cob	=	4600 lbf

A.1.3 – Support Analysis

Chase Bruno | Senior Project | 2-15-2014 | 1/

SUPPORT AT BEARINGS

GIVEN: FORCES @ BEARINGS

	F_x	F_y		W
BEARING 1	-612	1144	(lb_f)	.748 (in)
BEARING 2		985		.748
BEARING 3	[illegible]	622		.748
BEARING 4 IS NOT SUPPORTED BY THE HOUSING.				
BEARING 5		826		1.024
BEARING 6	133	265		1.024

* t of housing = .375 in

Material = ASTM CLASS 30 CAST IRON A = .375 in × bearing width

$S_u = 30\ ksi$

FIND: σ_1, S.F.

SOLN: $F/A = \sigma$ $A_{1-3} = .2805\ in^2$

$F_1 = \sqrt{-612^2 + 1144^2}$ $A_{5-6} = .384\ in^2$

$F_1 = 1302\ lb_f$

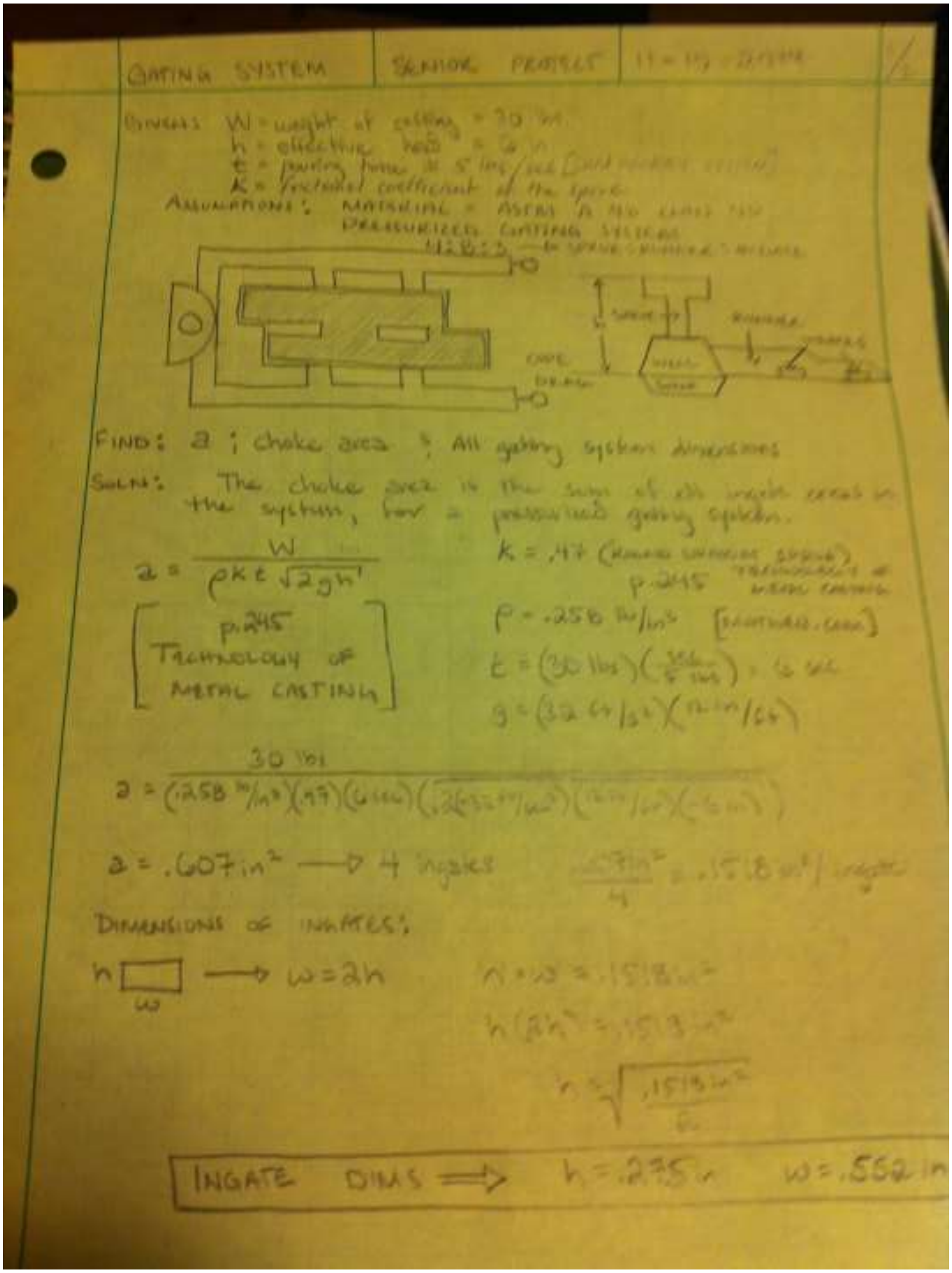
$\sigma_1 = \frac{1302\ lb_f}{.2805}$ $\sigma_1 = 4{,}642\ psi$

$S.F. = \frac{S_u}{\sigma_1} = \frac{30\ ksi}{4.64\ ksi} = 6.5$

$\boxed{S.F = 6.5}$

A.2 - Production

A.2.1 - Mold Design


GATING SYSTEM | SENIOR PROJECT | 1/2

GIVENS: W = weight of casting = 30 lbs
h = effective head
t = pouring time
k = frictional coefficient of the sprue

ASSUMPTIONS: MATERIAL = ASTM A 48 CLASS
PRESSURIZED GATING SYSTEM

FIND: a ; choke area & All gating system dimensions

SOL'N: The choke area is the sum of all ingate areas in the system, for a pressurized gating system.

$a = \frac{W}{\rho k t \sqrt{2gh}}$

[p. 245 TECHNOLOGY OF METAL CASTING]

k = .47

p. 245

$\rho = .258$ lb/in³

$a = \frac{30 \text{ lbs}}{(.258 \text{ lb/in}^3)(.47)(6 \text{ sec})(\ldots)}$

$a = .607 \text{ in}^2 \longrightarrow 4$ ingates

$\frac{.607 \text{ in}^2}{4} = .1518 \text{ in}^2$/ ingate

DIMENSIONS OF INGATES:

$h \; \boxed{} \longrightarrow w = 2h$

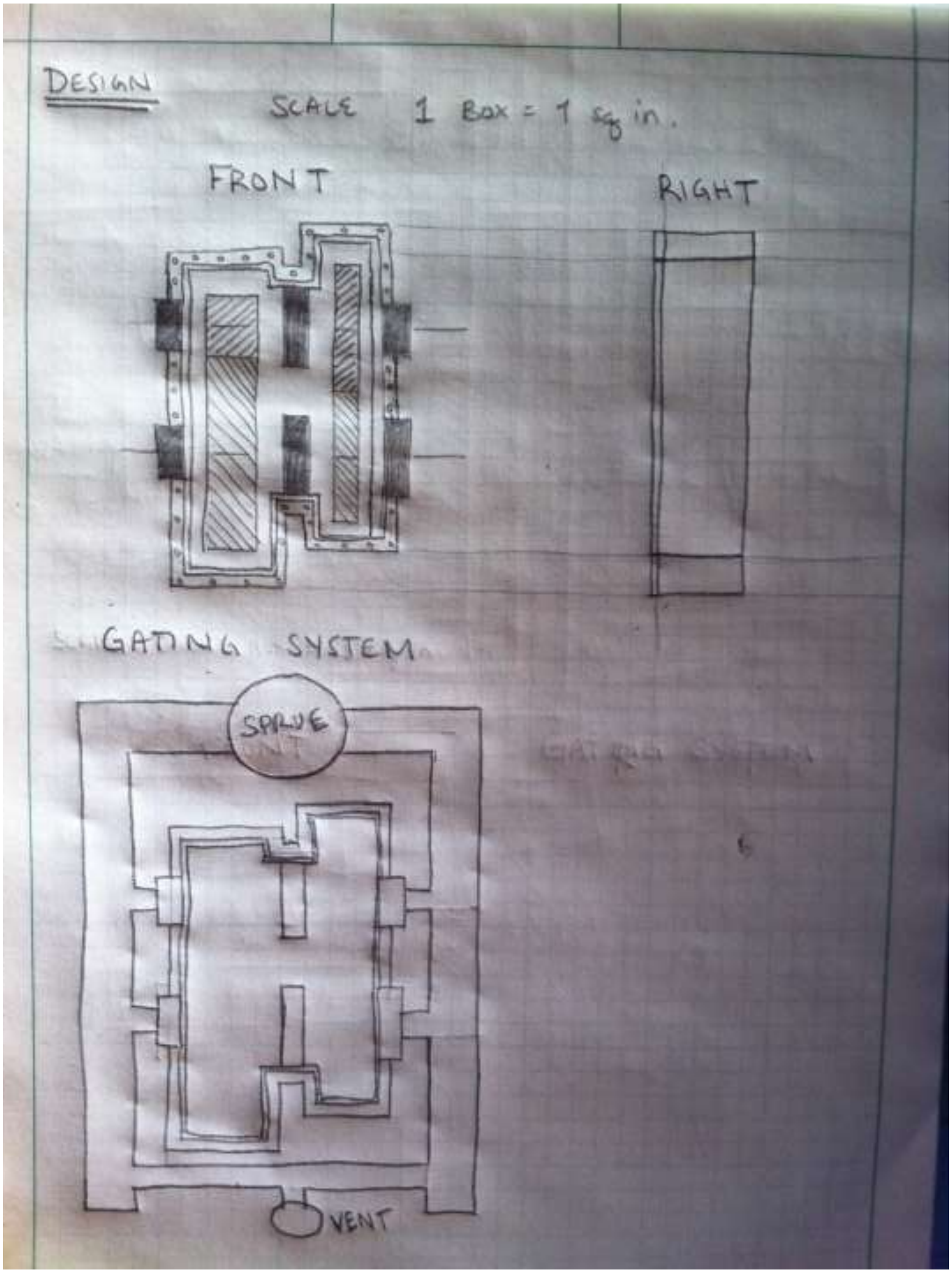
$h \cdot w = .1518 \text{ in}^2$

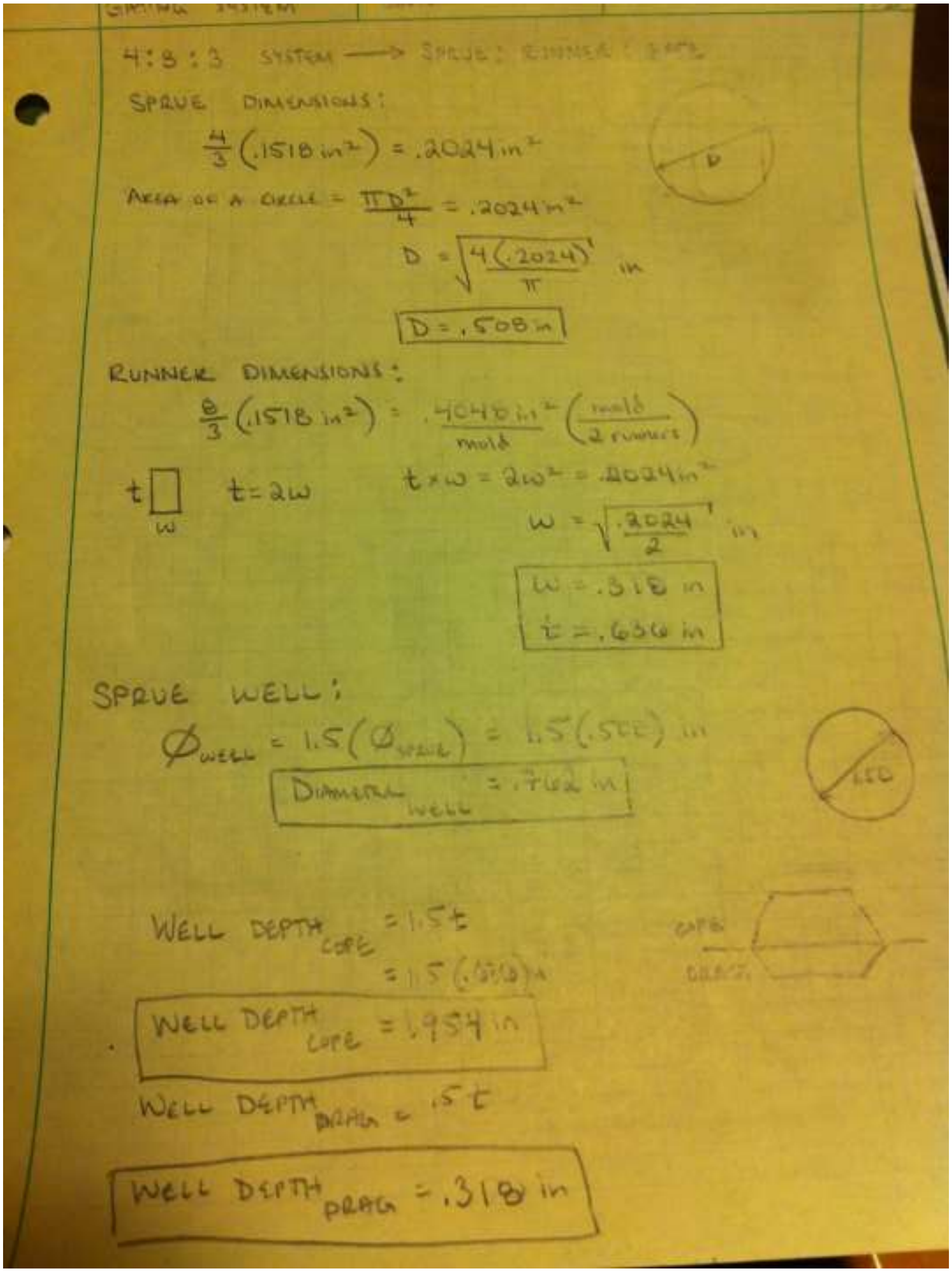
$h(2h) = .1518 \text{ in}^2$

$h = \sqrt{\frac{.1518 \text{ in}^2}{2}}$

$\boxed{\text{INGATE DIMS} \Longrightarrow h = .275 \text{ in} \quad w = .552 \text{ in}}$

A.2.2 – Gating Design





GATING SYSTEM

4:8:3 SYSTEM → SPRUE : RUNNER : GATE

SPRUE DIMENSIONS:

$$\frac{4}{3}(.1518\,in^2) = .2024\,in^2$$

AREA OF A CIRCLE = $\frac{\pi D^2}{4} = .2024\,in^2$

$$D = \sqrt{\frac{4(.2024)}{\pi}}\ in$$

$$\boxed{D = .508\,in}$$

RUNNER DIMENSIONS:

$$\frac{8}{3}(.1518\,in^2) = \frac{.4048\,in^2}{mold}\left(\frac{mold}{2\ runners}\right)$$

$t = 2w$

$$t \times w = 2w^2 = .2024\,in^2$$

$$w = \sqrt{\frac{.2024}{2}}\ in$$

$$\boxed{\begin{array}{l} w = .318\ in \\ t = .636\ in \end{array}}$$

SPRUE WELL:

$$\varnothing_{well} = 1.5(\varnothing_{sprue}) = 1.5(.508)\ in$$

$$\boxed{Diameter_{well} = .762\ in}$$

$$Well\ Depth_{cope} = 1.5t = 1.5(.636)\ in$$

$$\boxed{Well\ Depth_{cope} = .954\ in}$$

$$Well\ Depth_{drag} = .5t$$

$$\boxed{Well\ Depth_{drag} = .318\ in}$$

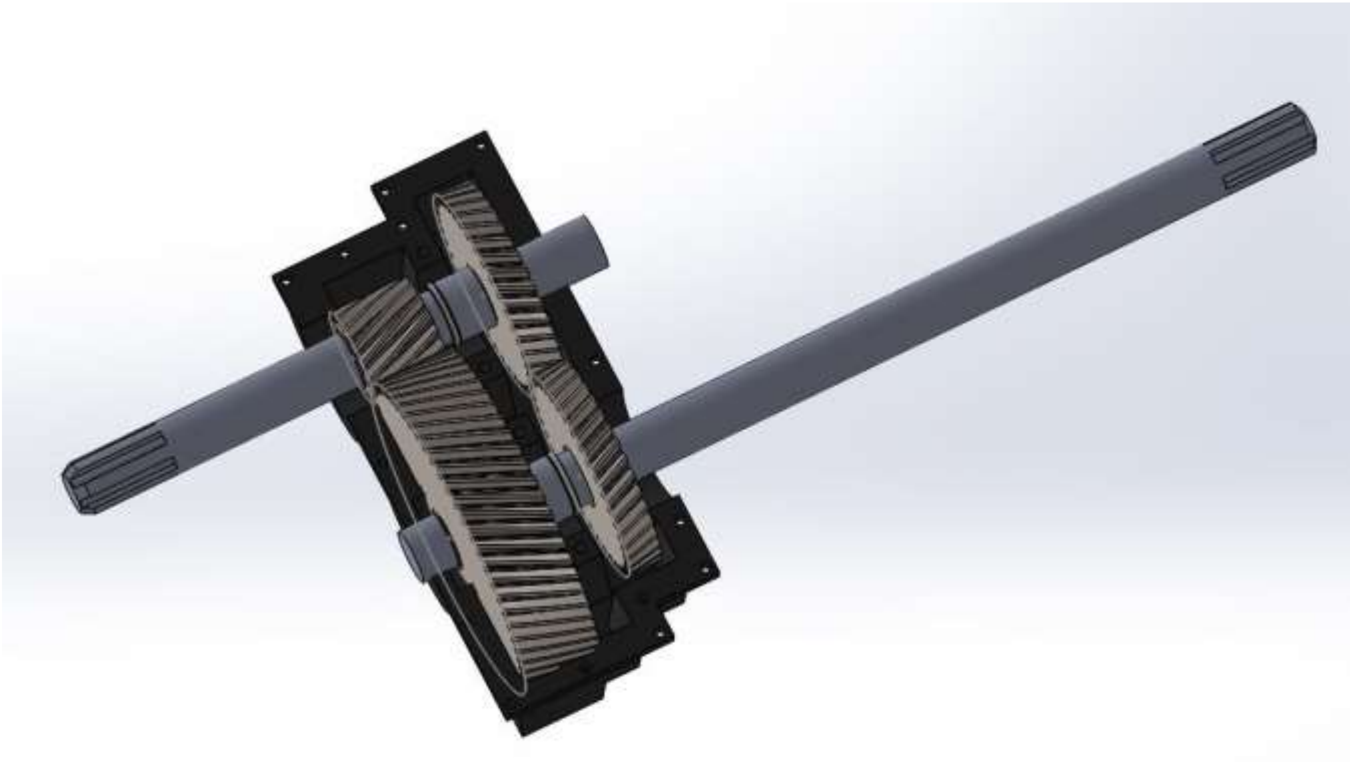
A.2.3 – Gating Design Summary Table

4:8:3 Gating System Spreadsheet									
Inputs					Outputs				
DESIGN1									
Weight of Casting	W	24.708	lbs		Choke Area	a	1.567	in^2
Density of Material	ρ	0.260	lbs/in^3		Ingate Height	hI	0.443	in
Effective Head	h	6.000	in		Ingate Width	wI	0.885	in
Pouring rate	dt	13.000	lbs/sec		Sprue Diameter	Ds	0.816	in
Frictional Coefficient of the Sprue	k	0.470	p. 245		Runner Height	hR	0.723	in
Gravity	g	32.000	ft/sec^2		Runner Width	wR	0.361	in
Number of Ingates	I	4.000	Ingates		Well Diameter	Dw	1.223	in
Number of Runners	R	2.000	Runners		Cope Well Depth	dcw	1.084	in
Number of Sprues	S	1.000	Sprues		Drag Well Depth	ddw	0.361	in
DESIGN2									
Weight of Casting	W	24.708	lbs		Choke Area	a	0.602	in^2
Density of Material	ρ	0.260	lbs/in^3		Ingate Height	hI	0.274	in
Effective Head	h	6.000	in		Ingate Width	wI	0.549	in
Pouring rate	dt	5.000	lbs/sec		Sprue Diameter	Ds	0.506	in
Frictional Coefficient of the Sprue	k	0.470	p. 245		Runner Height	hR	0.448	in
Gravity	g	32.000	ft/sec^2		Runner Width	wR	0.224	in
Number of Ingates	I	4.000	Ingates		Well Diameter	Dw	0.759	in
Number of Runners	R	2.000	Runners		Cope Well Depth	dcw	0.672	in
Number of Sprues	S	1.000	Sprues		Drag Well Depth	ddw	0.224	in

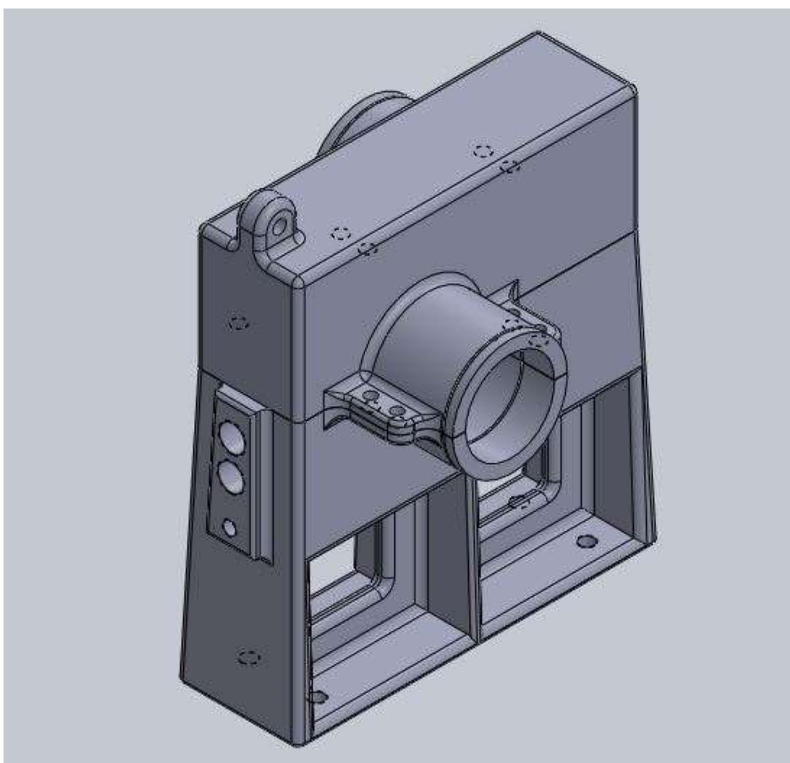
APPENDIX B – Drawings

B.1 – Design Evolution

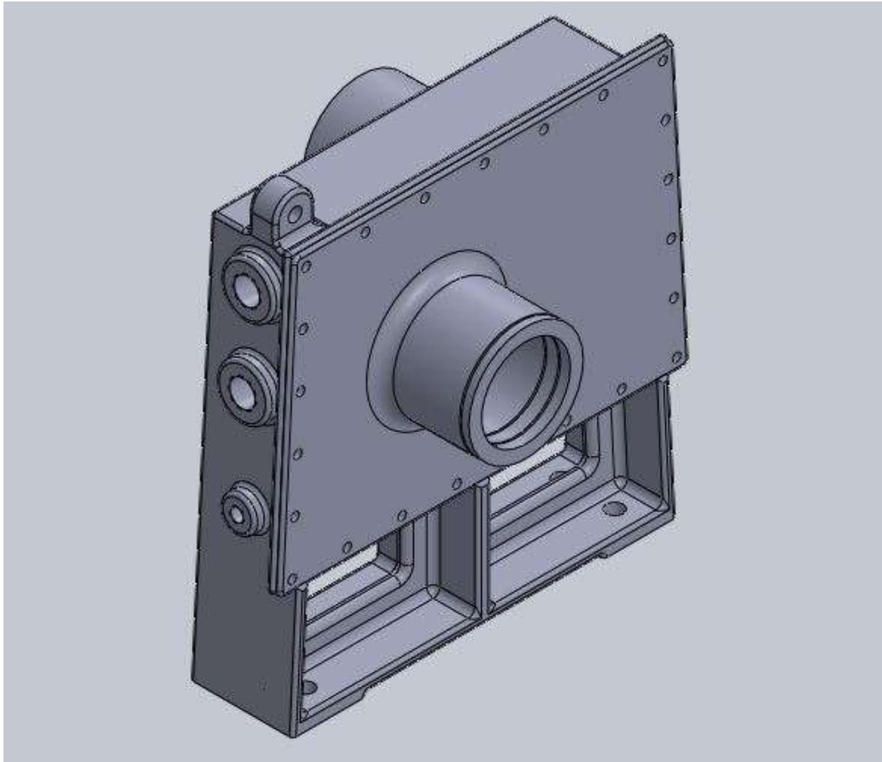
B.1.1 – Design 1



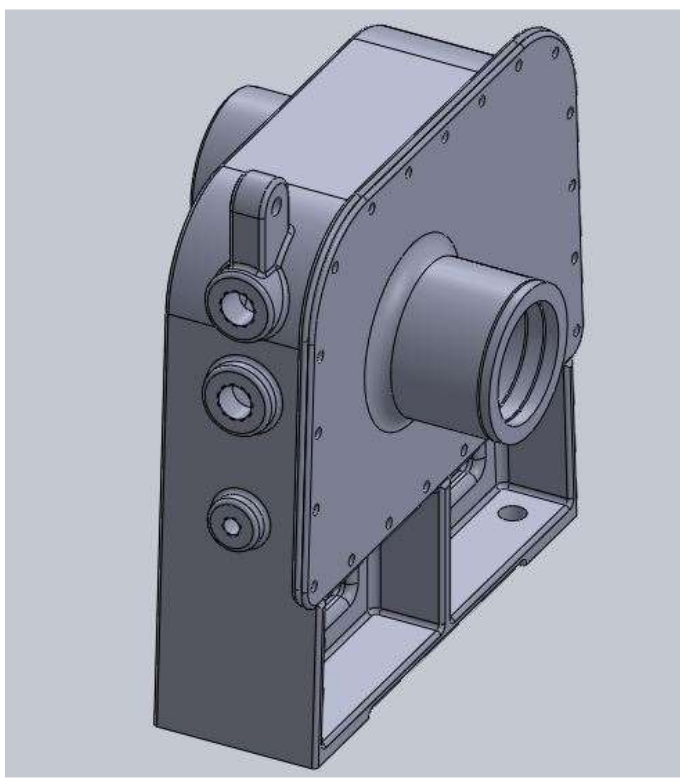
B.1.3 – Design 2



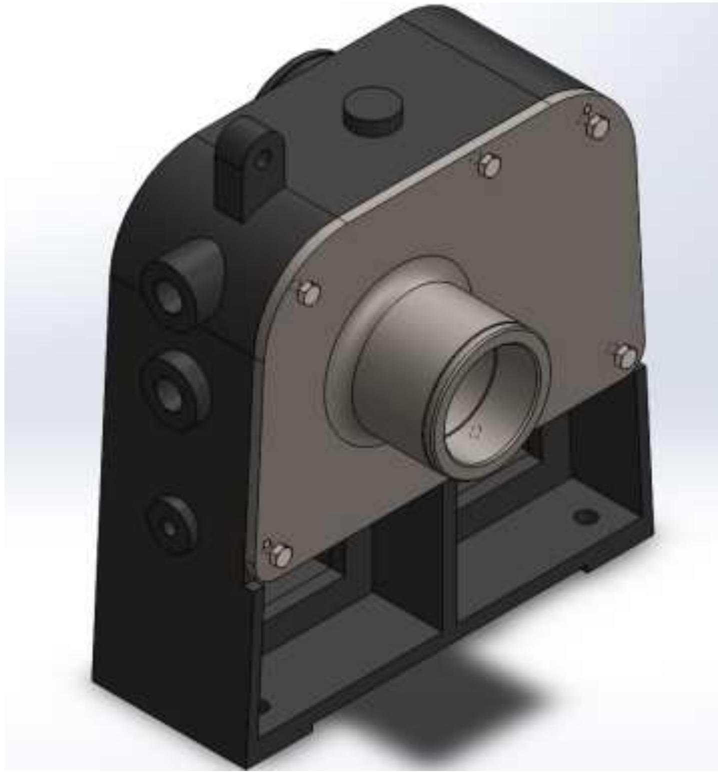
B.1.4 – Design 3



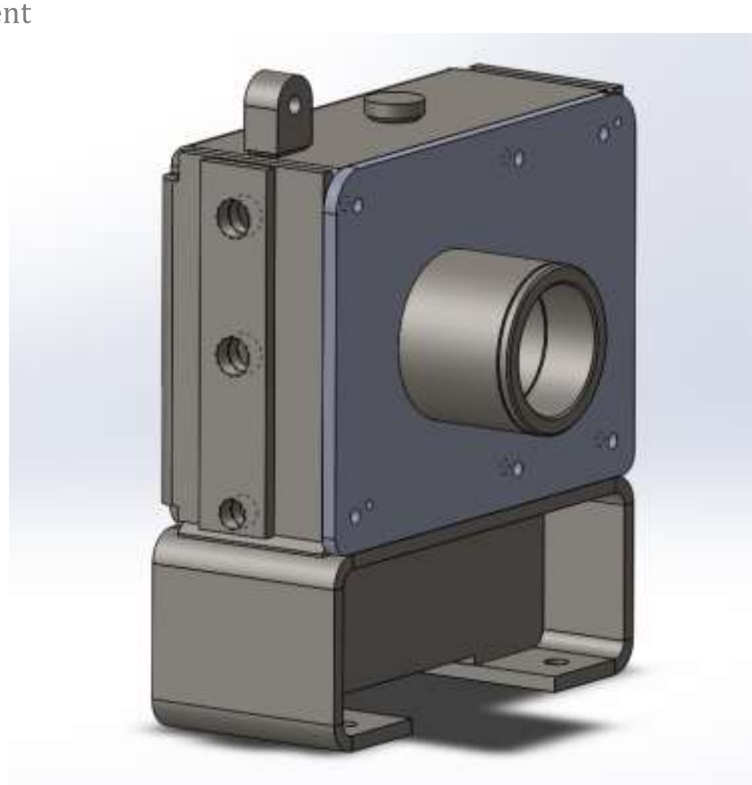
B.1.5 – Design 4



B.1.6 – Design 5



B.1.7 – Design 5 Weldment



B.2 – Cast Housing

Note:

All Drawings have been removed from the report to protect H.F. Hauff Company's proprietary information.

APPENDIX C – Parts List

Parts List

Part Number	Part Name	Drawing Number	LH/RH	Pd	Dp	N	Face	Hubbed
	Gear 1	G-001	LH	7.2500	8.0000	58.0000	1.2500	0.3640
	Gear 2	S-002	RH	7.2500	2.2070	16.0000	1.2500	
	Gear 3	G-003	LH	7.2500	5.1035	37.0000	0.7500	
	Gear 4	G-004	RH	7.2500	5.1035	37.0000	0.7500	

Part Number	Part Name	Drawing Number	Type	d x D x C	Bore	OD	Width	Static Load Rating	Dynamic Load Rating	Dynamic Load Calc.
209K	Bearing 1		Light 200K Series	45 x 85 x 19	1.7717	3.3465	0.748	4,600	8,150	
209K	Bearing 2	B-001	Light 200K Series	45 x 85 x 19	1.7717	3.3465	0.748	4,600	8,150	
209K	Bearing 3		Light 200K Series	45 x 85 x 19	1.7717	3.3465	0.748	4,600	8,150	
33110	Bearing 4	B-002	Tapered Roller	50 x 85 x 26	1.9685	3.3465	1.02362	3,220	3,710	
33110	Bearing 5		Tapered Roller	50 x 85 x 26	1.9685	3.3465	1.02362	3,220	3,710	
R22	Bearing 6	B-003	Standard Light Weight	1 3/8 x 2 1/2 x 7/16	1.3750	2.5000	0.4375	1,910	2,756	
22DU28	Garlock 1	B-004	DU Series	1 3/8 x 1 17/32 x 1 3/4	1.375	1.53125	6.250	PV Rating	PV Calc.	250 N/mm2
					Thickness:	0.078125		50,000	13,000	

Manufacturer	Part Number	Drawing Number	Part Name	Type	Shaft x Bore x Width	Lip Code	Material
Timken	558513XX	L-001	Seal 1	320	58 x 85->85.25 x 13		S: Nitrile
SR Seals	13529	L-002	Seal 2	HM14	1.3750 x 1.750 + .004 x .197	R	
Timken	658508XX	L-003	Seal 3	350	50 x 85->85.20 x 8		S: Nitrile

Part Number	Part Name	Drawing Number	Type	d x D	d	D	L1	L2	L3	B	D1
	Tollok 1	T-001	TLK 131	2 1/8	2.125	3.346	1.181	1.378	1.929	2.244	3.583
	Tollok 2	T-002	TLK 130	1 3/8	1.375	2.362	1.024	1.181	1.614	1.850	2.598

Part Number	Part Name	Drawing Number	Product	Material	Finish	ID	OD
	Shaft 1	S-001	Steel Round	4140	Chromed, Ground, and Polished		1.375
	Shaft 2	S-002	Steel Round	HT 4140 OQT 1000	Turned, Ground, and Polished		2.250
	Shaft 3	S-003	Round Mechanical Tubing	1020	Turned, Ground, and Polished	1.500	2.750

Part Number	Part Name	Drawing Number	Product	Material	ID	OD	t	lb/ft
	Housing	H-001	3/8" Plate	1008/1010 HR			0.375	15.32
			4 3/8" Round Mechanical Tubing	1020 CD	3.25	4.5	0.625	25.87
	Plate	H-002	3/8" Plate	1008/1010 HR			0.375	15.32
			4 3/8" Round Mechanical Tubing	1020 CD	3.25	4.5	0.625	25.87
	Base	H-003	3/8" Plate	1008/1010 HR			0.375	15.32
	Tab	H-004	1" Square Bar	1018 CD		1X1		3.4
	Fill/Vent Boss		2" Steel Round	1018 CD		2		10.68
	Spy Hole Boss		2" Steel Round	1018 CD		2		10.68
	Drain Plug Boss		2" Steel Round	1018 CD		2		10.68

APPENDIX D – Budget

Budget

Part Number	Part Name	LH/RH	Pd	Dp	N	Face	Hubbed			Estimated cost	Vendor
Gear 1	Gear 1	LH	7.2500	8.0000	58.0000	1.2500	0.3640		$	1,247.50	TBD
Gear 2	Gear 2	RH	7.2500	2.2070	16.0000	1.2500			$	-	*See Shaft 2*
Gear 3	Gear 3	LH	7.2500	5.1035	37.0000	0.7500			$	997.50	TBD
Gear 4	Gear 4	RH	7.2500	5.1035	37.0000	0.7500			$	997.50	TBD
								Subtotal	$	3,242.50	

Part Number	Part Name	Type	d x D x C			Cost	Vendor
209K	Bearing 1	Light 200K Series	45 x 85 x 19		$	45.68	amazon.com
209K	Bearing 2	Light 200K Series	45 x 85 x 19		$	45.68	amazon.com
209K	Bearing 3	Light 200K Series	45 x 85 x 19		$	45.68	amazon.com
33110	Bearing 4		50 x 85 x 26		$	31.37	amazon.com
33110	Bearing 5		50 x 85 x 26		$	31.37	amazon.com
R22	Bearing 6	Standard Light Weight	1 3/8 x 2 1/2 x 7/16		$	12.95	VXB.com
22DU28	Garlock 1	DU Series	1 3/8 x 1 17/32 x 1 3/4		$	7.41	GGB
				Subtotal	$	220.14	

Manufacturer	Part Number	Part Name	Type	Shaft x Bore x Width			Cost	Vendor
Timken	588513XX	Seal 1	320	58 x 85->85.25 x 13		$	9.08	RTC Farms
SR Seals	13529	Seal 2	HM14	1.3750 x 1.750 + .004 x .197		$	4.89	RTC Farms
Timken	658508XX	Seal 3	350	50 x 85->85.20 x 8		$	10.98	thewrenchmonkey.com
					Subtotal	$	24.95	

Part Number	Part Name	Type	d x D			Cost	Vendor
Tollok 1	Tollok 1	TLK 131	2 1/8		$	69.50	McGuire Bearing Company
Tollok 2	Tollok 2	TLK 130	1 3/8		$	62.75	McGuire Bearing Company
				Subtotal	$	132.25	

Part Number	Part Name	Product	Material	Finish	ID	OD	$/lb		Cost	Vendor
Shaft 1	Shaft 1	Steel Round	4140	Chromed, Ground, and Polished		1.375	$ 3.25	$	37.67	Pacific Steel and Recyling
Shaft 2	Shaft 2	Steel Round	HT 4140 OQT 1000	Turned, Ground, and Polished		2.250		$	1,500.00	TBD
Shaft 3	Shaft 3	Round Mechanical Tubing	1020	Turned, Ground, and Polished	1.500	2.750	$ 3.64	$	82.93	Pacific Steel and Recyling
							Sub Total:	$	1,620.60	

Part Number	Part Name	Product	Material	ID	OD	t	lb/ft	$/lb		Cost	Vendor
Housing	Housing	3/8" Plate	1008/1010 HR			0.375	15.32	$ 0.77			Pacific Steel and Recyling
		4 3/8" Round Mechanical Tubing	1020 CD	3.25	4.5	0.625	25.87	$ 3.24			Pacific Steel and Recyling
Base	Base	3/8" Plate	1008/1010 HR			0.375	15.32	$ 0.77			Pacific Steel and Recyling
Tab	Tab	1" Square Bar	1018 CD		1X1		3.4	$ 1.00	$	476.70	Pacific Steel and Recyling
Fill/Vent Boss	Fill/Vent Boss	2" Steel Round	1018 CD		2		10.68	$ 1.91			Pacific Steel and Recyling
Spy Hole Boss	Spy Hole Boss	2" Steel Round	1018 CD		2		10.68	$ 1.91			Pacific Steel and Recyling
Drain Plug Boss	Drain Plug Boss	2" Steel Round	1018 CD		2		10.68	$ 1.91			Pacific Steel and Recyling
Plate	Plate	3/8" Plate	1008/1010 HR			0.375	15.32	$ 0.77	$	99.45	Pacific Steel and Recyling
		4 3/8" Round Mechanical Tubing	1020 CD	3.25	4.5	0.625	25.87	$ 3.24			Pacific Steel and Recyling
								Sub Total:	$	576.14	

Total Cost $ 5,816.59

APPENDIX E – Schedule

Project Schedule

Gear Drive System
Ricky Skinner
Casey McFarlen
Gabe Bruno

Task Number	Description	Duration (hr.) Estimated	Actual	January	February	March	April	May	June	% Complete
1	**Proposal/Drawings**									
1a	Discuss/Finalize design with Hauff	50	50.2							
1b	Make solidworks Drawings	60	80.6							
1c	Discuss and Finalize drawings with Hauff	5	10.3							
1d	Discuss machining options with hauff	5	10.8							
1e	Send drawings to selected machine shop for pricing	1								
1f	Discuss received price quote with hauff for approval	2								
1g	Final Budget Approval	1								
1h	Proposal Completion	5								
2	**Construction**									
2a	Order shaft material, bearings,seals,misc.	2								
2b	Order Gears 1,3,4	2								
2c	Order plate for fabricated box	2								
2d	Order pipe for fabricated box	2								
2e	Order upper shaft w/ gear 2 through machine shop	2								
2f	Request tour of 5-axis CNC machine shop	1								
2g	Go tour 5-axis machine shop (hopefully)	4								
2h	Help with machining where needed/learn from jorge	↓								
2h(1)	Machine shaft OD	3								
2h(2)	Machine hollow shaft ID	1								
2h(3)	Machine ring grooves	1								
2h(4)	Grind hollow shaft	5								
2i	Cut pipe for housing	1								
2j	laser cut housing parts	2								
2k	bend plate for housing	2								
2l	weld housing	2								

Deliverables:
- Final Proposal
- 5-axis machine shop tour
- Gear Box Assembly
- Final Report
- Final Video Presentation

2m	Gear Box Assembly		
2m(1)	Attach sleeve bearing to hollow shaft	1	
2m(2)	Insert Frozen input shaft into sleeve bearing/hollow shaft	1	
2m(3)	place bearings onto hollow and upper shafts	1	
2m(4)	Secure bearing/shaft assemblied into either housing boss	2	
2m(5)	Secure tollok and large gear onto input shaft	1	
2m(6)	Palce hot bearing sleeve and bearing onto end of input shaft	1	
2m(7)	Attach upper gear onto upper shaft	0.5	
2m(8)	Fit upper and lower shaft assemblies together in housing	2	
2m(9)	Seal housing	1	
2m(10)	Fill housing with gear oil	0.5	
2n	Update Web Page	2	
3	**Testing**		
3a	Discuss testing apparatus with Hauff	5	
3b	Design testing apparatus	15	
3c	Build testing apparatus	8	
3d	Select tractor for testing	1	
3e	Set up testingdevice with data recorders	2	
3f	Live test run	5	
3g	Update Web Page	2	
4	**Documentation**		
4a	Outline Report	2	
4b	Create Report	10	
4c	Outline presentatioin	2	
4d	Create PowerPoint	2	
4e	Narrative Video	8	
4f	Update Web Page	5	
5	**Research**		
5a	shaft material	3	
5b	Machining Processes	8	
5c	CNC code writing	5	
5d	polishing/grinding	5	
	Total Hours	262	151.9

Figure E1

Appendix F - Expertise and Resources

Production:

Tim Craig

North Star Casteel

820 Bradford Street

Seattle, WA

Machining:

Ted Bramble

CWU

Neil Hauff

H.F. Hauff Inc.

2921 Sutherland Dr, Yakima, WA

(509) 248-0318

Appendix G – Evaluation Sheet

Evalution sheet

Visual Inspection Data

Name:

Date:

4 hours
Metalic Flakes
none little moderate excesive extreme
Oil Discoloration
none milky gray dark black

8 hours
Metalic Flakes
none little moderate excesive extreme
Oil Discoloration
none milky gray dark black

12 hours
Metalic Flakes
none little moderate excesive extreme
Oil Discoloration
none milky gray dark black

16 hours
Metalic Flakes
none little moderate excesive extreme
Oil Discoloration
none milky gray dark black

20 hours
Metalic Flakes
none little moderate excesive extreme
Oil Discoloration
none milky gray dark black

24 hours
Metalic Flakes
none little moderate excesive extreme
Oil Discoloration
none milky gray dark black

28 hours
Metalic Flakes
none little moderate excesive extreme
Oil Discoloration
none milky gray dark black

32 hours
Metalic Flakes
none little moderate excesive extreme
Oil Discoloration
none milky gray dark black

36 hours
Metalic Flakes
none little moderate excesive extreme
Oil Discoloration
none milky gray dark black

40 hours
Metalic Flakes
none little moderate excesive extreme
Oil Discoloration
none milky gray dark black

44 hours
Metalic Flakes
none little moderate excesive extreme
Oil Discoloration
none milky gray dark black

48 hours
Metalic Flakes
none little moderate excesive extreme
Oil Discoloration
none milky gray dark black

Appendix H – Testing Report

1.1 SCOPE

The Victair Mistifier gearbox was run at 540 rpm and powered using the PTO off an 80 HP tractor. The gearbox and fans were mounted to a stationary cart while being tested. Spray was not used during the testing. The gearbox was powered for two testing periods.

The gearbox was constructed with mock gears. The design calls for helical gears. However, for initial testing laser cut spur were made out of ¼” steel plate and bolted together to achieve the same dimensions as the helical designed gears.

Temperature data was taken in six locations every 15 seconds while power was feed into the gearbox. The data was acquired using a Fluke Hydra Logger device and Logger software. An infrared temperature gun gave us additional temperature data. An airspeed pitot measured the airspeed out of the fans.

1.2 SUMMARY OF RESULTS

	Targeted Value	Test Run 1	Test Run 2
Airspeed	104 mph	104 mph	104 mph/ 40 mph
Input Shaft Temperature	< 170	245	110
Hollow Shaft Temperature	< 170	245	110
Gearbox Temperature	< 170	90 (Outside Box)	107 (Oil Temp)

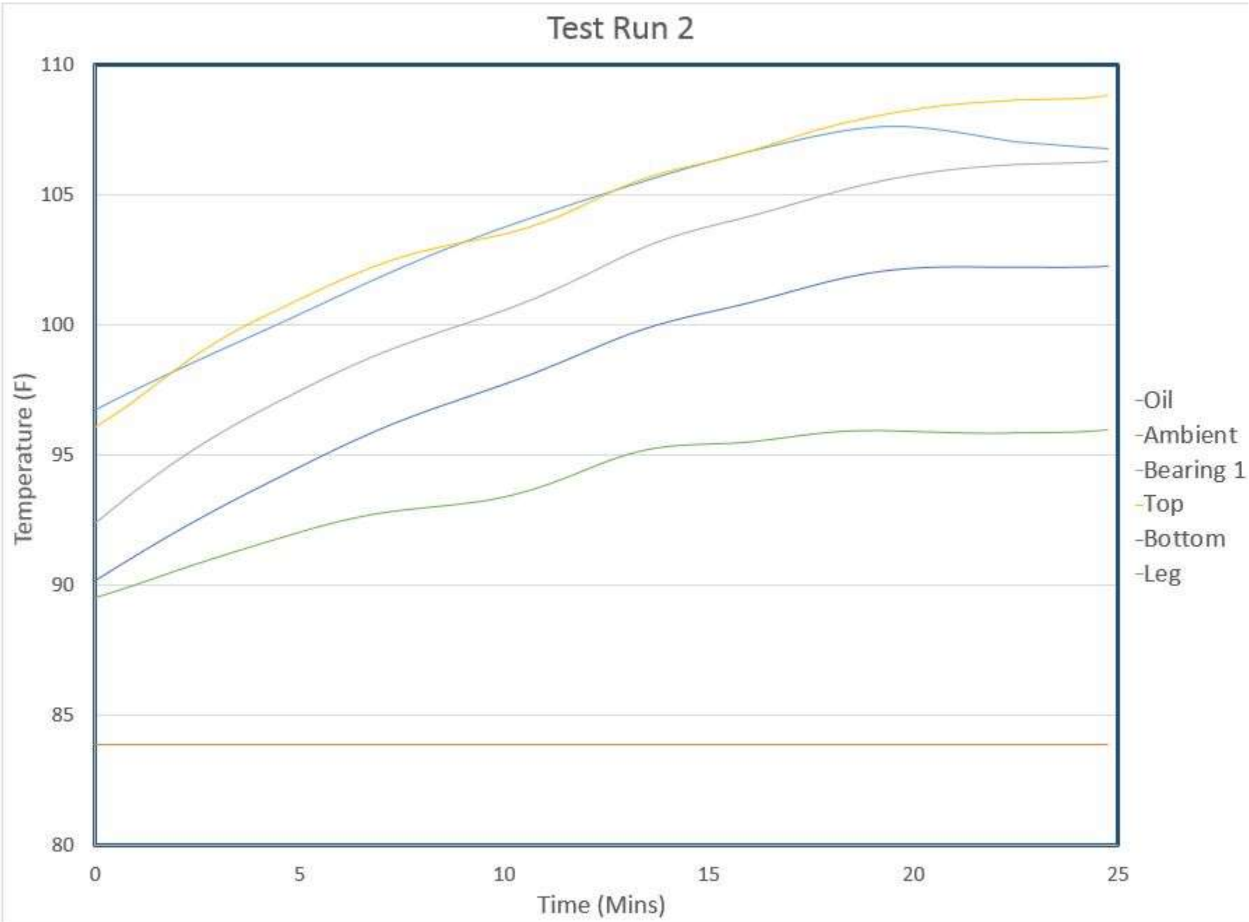
Test Run 1

The gearbox ran under full load with both fans. The concept of the design was proved to be valid. The test period was cut short, due to excessive heat at the input shaft and hollow shaft. It was predetermined that there would be added friction at the input and hollow shaft locations. This was due to a machining error in the hollow shaft. The inner diameter of the hollow shaft bore was not to spec. When the plain surface bearings were assembled into the hollow shaft, the input shaft no longer fit through. The Teflon surface of the bearings had to be bored out in order for the input shaft to fit through the hollow shaft. Furthermore, the outside diameter of the hollow shaft was also off by a few thousandths. It caused the keyless hub to fit tighter on the shaft. This added force crushed the hollow shaft and clamped down on to the input shaft.

Even with the machining errors, the gearbox design functioned correctly and dissipated the heat generated by the gears and bearings.

Test Run 2

Fan 2 was removed from the gearbox. The Hydra Logger was set up and temperature data was acquired. The gearbox operated effectively, until the climax keyless hub gave out. It did not live up to the specifications that were provided by the manufacturer. Furthermore, there was oversight on the design when considering the heat expansion of the hubs themselves. The test determined that a design revision must occur at the keyless hubs.



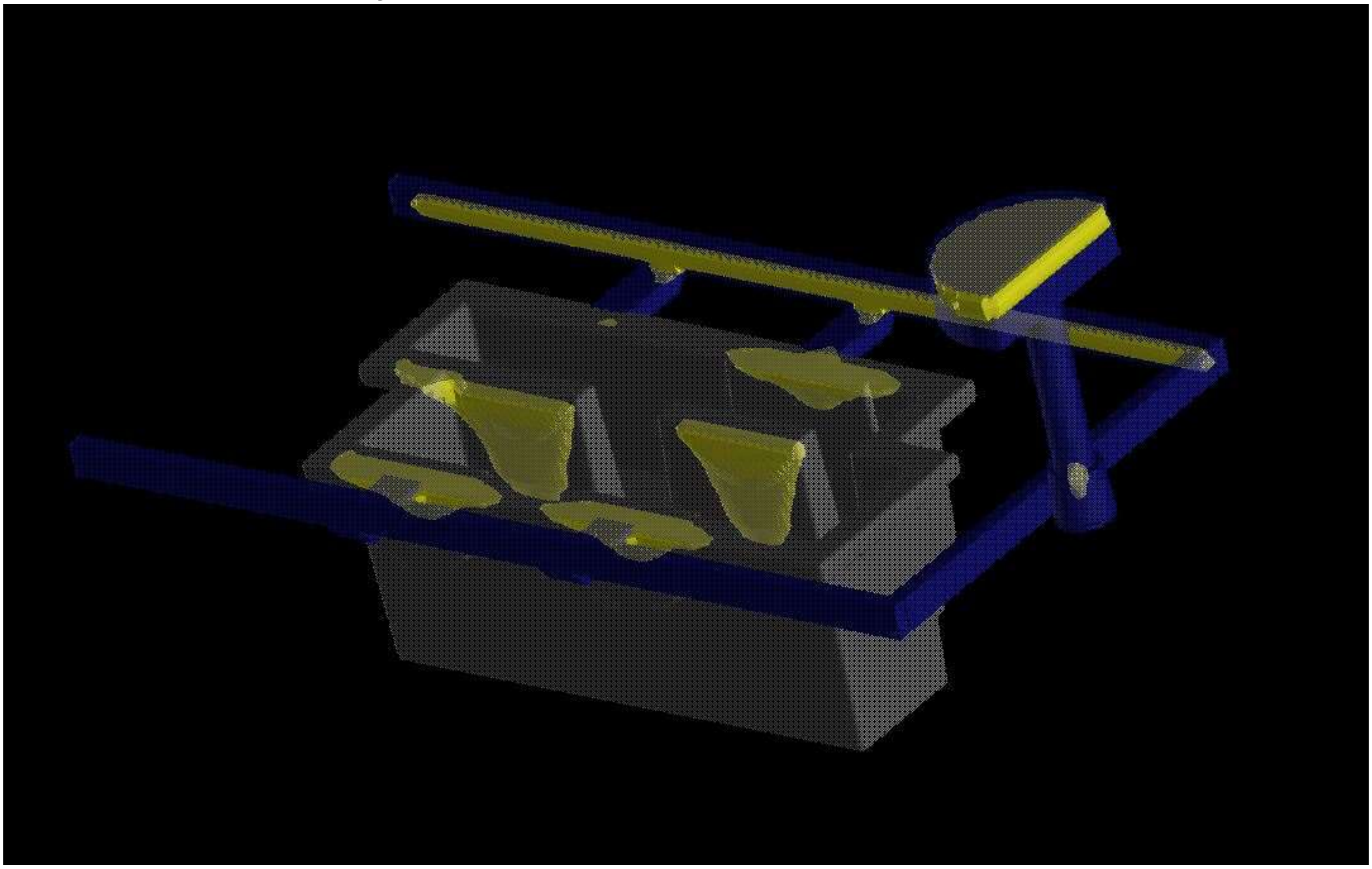
1.3 CONCLUSION

The testing validated the gearbox concept and design. Revisions to the design are necessary to insure success. Climax keyless hubs are not adequate for the design. They are to be replaced by splines. A new sleeve will be manufactured for the input shaft that will have splines on it. Gear 1 will be splined to the sleeve and the sleeve will be shrink fit to the input shaft. Fan 2 hub will be splined to Hollow Shaft. It is necessary for Hollow shaft to increase in outside diameter to accommodate the splines. Therefore, the cover boss will have to be bored out to a larger diameter. Consequently, new Timken taper bearings will have to be selected to accommodate the larger outside diameter of the Hollow Shaft.

APPENDIX I – Testing Data

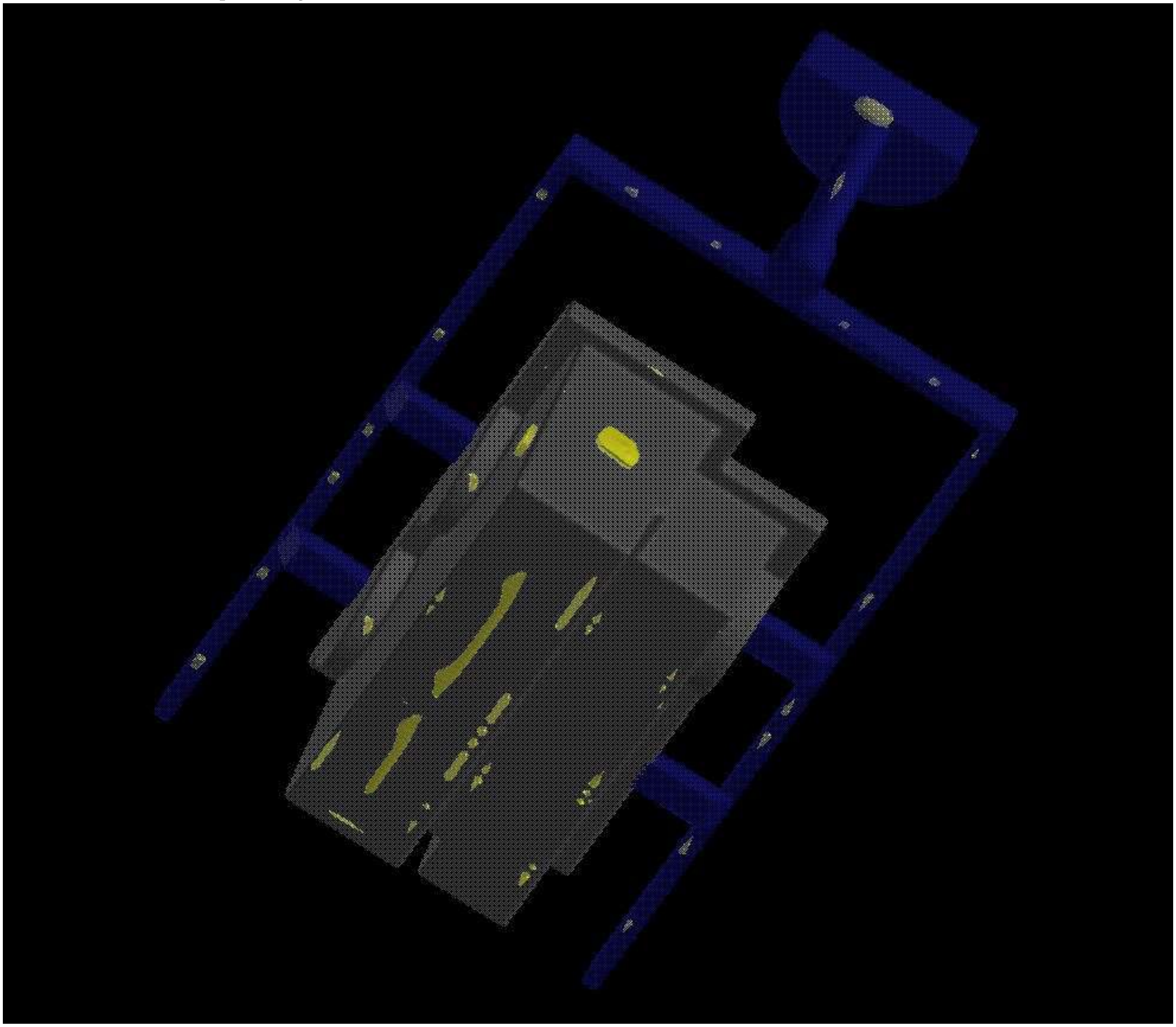
I.1. - SolidCast

I.1.1 – Material Density



Material Density

I.1.2. - Microporosity



Microporosity

I.2 – Data Sheets

APPENDIX J – Resume

Gabe Bruno
brunog@cwu.edu | 415.309.9122| Ellensburg, WA

Objective
To work with an innovative engineering team. I'd like the opportunity to use my knowledge in applied physics and mechanical assembly in conjunction with my leadership, communication and teamwork skills. I'm eager to begin my career in engineering and am confident I will be an asset to your business.

Education
Central Washington University - *Ellensburg, WA* Mar. 2012 – Jun. 2015

- B.S. in Mechanical Engineering Technology
    - Minor in Mathematics
- Applicable Courses: Thermodynamics, Heat Transfer, Fluid Mechanics, Technical Writing, Strengths of Materials, Statics, Dynamics

Butte College - *Oroville, CA* Jan. 2010 – Dec. 2011

- A.A. Degree in Social Behaviors

City College of San Francisco - *San Francisco, CA* Aug. 2008 – Dec. 2009

- A.S. Degree in Automotive Technology

Work Experience
Engineer Intern Jul. 2014 – Sep. 2014
North Star Casteel Products, Inc. - Seattle, WA

- Used Odyssey (Foundry Software) to better company organization, specifically to tooling storage.
- Provided Product Cost Analysis for multiple products
- Headed the reengineering of a pouring mechanism. Drafted drawings for pattern maker.
- Researched and helped the Maintenance Engineer reengineer the foundry's Air Filtration System.
- Compiled a concise report that planned the revamping of the No-Bake Line. Communicated directly with the Head of Sales, Foundry Manager, and Maintenance Engineer to effectively create the report.

Collegiate Athlete - Football Jan. 2010 – Jun. 2014
Central Washington University, Butte College

- Team Captain, All-State Academic Football Team, Most Valuable Defensive Lineman (2011)
- Academic All-GNAC (Conference) Team (2013)
- Reliable and organized in managing a balanced schedule between school and football
- Self-motivated to compete at a high level
- Practice discipline, work-ethic, integrity and punctuality
- Valued leader and communicative team player

Certificates
CCSF: General Technician, Transmission Specialist, Engine Specialist; ASE: Electrical Technician
President, AFS CWU Chapter; Vice President, MCA Club

Skills

- AutoCad 2013, SolidWorks CSWA, Microsoft Office, GD&T
- Excellent written and verbal communication. Proficient communication in Spanish.
- Proficient in PLC wiring, programming, and applications
- Assertive, goal-oriented, cooperative, works great under pressure
- Valid WA Driver's License